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Home range and factors affecting the appearance of the fishing cat (*Prionailurus viverrinus*) in a human-dominated landscape, Thailand

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Abstract

A study on the size of the home range and factors affecting the appearance of the fishing cats using satellite collars at Khao Sam Roi Yot Wetland (KSRYWL), Prachuap Khiri Khan Province, Thailand was conducted from June 2022 to February 2024. This study aimed to determine the size of the home range and factors affecting the appearance of this species. Twelve fishing cats, five adult males and seven adult females, were trapped and tagged with satellite collars. The average home range size based on Autocorrelated Kernel Density Estimation (AKDE) of male and female were 6.29 km^2 (range 3.40–9.69 km^2) and 2.83 km^2 (range 1.35–5.25 km^2), respectively. The study's results found that factors affecting the appearance of fishing cats were topographic factors, including Elevation Slope, NDVI, and anthropogenic factors, including distance to villages, distance to aquaculture, and distance to abandoned aquaculture, which were significantly significant. The results of the comparative study between male and female leopard fish found that the factor. Distance to aquaculture had a greater effect on the presence of male leopard fish than female leopard fish, meaning that male leopard fish are more vulnerable to threats from humans. The findings of this study can be used for habitat protection and management activities related to species conservation.

Keywords: Autocorrelated Kernel Density Estimation; Khao Sam Roi Yot Wetland; satellite collars; step-selection functions

Introduction

Various human activities near urban environments increasingly impact mid-sized felids and other mammalian carnivores (Kowalski et al., 2015; Decœur et al., 2023). Urban expansion and rising human activity in and around preserved habitats may lead to shifts in the spatial distributions of these species (Kowalski et al., 2015; Chang et al., 2023; Ren et al., 2023; Broquet et al., 2024). The sensitivity of mammalian carnivores to urbanization varies by species, with some disappearing from fragmented landscapes, while others show greater tolerance to human disturbances (Łopucki et al. 2019).

The fishing cat is classified as a medium-sized wild cat belonging to the family Felidae (Chakraborty et al., 2020). It is predominantly found in South and Southeast Asia. It is classified as a vulnerable species (IUCN, 2024), with a critically endangered status in the national conservation status of Thailand (Office of Natural Resources and Environmental Policy and Planning, 2023). Fishing cats show a discontinuous population distribution in mangroves, wetlands, rivers, and swamps in South and Southeast Asia (Mukherjee et al. 2016). The species are at a high risk of extinction and are thought to be among the most vulnerable of the medium-sized wild cats in Southeast Asia (Mukherjee et al., 2016), possibly due to the very low overlap of their occupied habitat with protected areas and other conservation interventions, rather than an inherently higher susceptibility shown by the other small cats (Duckworth et al., 2014).

Fishing cats are primarily nocturnal but may also be active during the day (Ganguly & Adhya, 2022). Unlike other cat species, the fishing cat is unique because 70% of its diet consists of fish (Adhya et al., 2024; Wongson et al., 2024). It also feeds on birds and insects (Wongson et al., 2024). The home range of a male individual fishing cat is larger (16 to 22 km^2) than a female (4 to 8 km^2) (Cutter, 2015). Like other wild carnivore species worldwide, fishing cats in the Khao Sam Roi Yot Wetland (KSRYWL) are significantly impacted by human activities such as agricultural expansion, housing development, and infrastructure in their habitats (Phosri et al., 2021; Bombieri et al., 2023). These factors threaten the survival of the fishing cat population (Chowdhury et al., 2015). Anthropogenic disturbance is introduced to the landscape, and it can influence the movement of animals and the spatiotemporal distribution (Xiang et al., 2019;

Cowan et al., 2024). Understanding how the species relate spatially to the environment and human disturbances is critical to assigning areas for conservation and developing conservation strategies (Nagy-Reis et al. 2017). Adhya et al. (2022) reported that important factors that affected the identifying priority areas for the conservation of fishing cats are wetlands (18.36%) and elevation (17.15%) are the most important variables determining the ecological niche of the fishing cat. Identifying factors influencing the distribution of and interactions within carnivore communities is important for understanding how they are affected by human activities (Carricondo-Sanchez et al., 2019).

Studies on factors related to the species' apparent presence in the area using satellite collars are essential knowledge for management that is still lacking. Therefore, understanding the home range size and habitat selection in areas with prominent human activity is crucial for managing and conserving the environment and the endangered fishing cat population in the changing environment. The objective of this study was to examine the home range size of fishing cats in the most critical conservation areas in Thailand using radio satellite signals and to analyze factors affecting their appearance. The results can be used to inform habitat management strategies for the conservation of fishing cats in changing environments.

Martial and methods

Ethics statement

This study was conducted with permission from the Department of National Parks, Wildlife and Plant Conservation (License No. 0909.204/10153, dated May 20, 2022) as part of a project on the ecology of fishing cats using radio satellite collars in the area surrounding Khao Sam Roi Yot National Park (KSRYNP). The research was also approved by the Office of the National Research Council (Permission Document No. 0401/9980, dated June 7, 2022). Additionally, the researchers possess certification for completing animal rights training in experimental work from the Office of the National Research Council, Thailand.

Study Area

Covering approximately 98 km², the KSRY is located on the coast of the Prachuap Khiri Khan Province. It was the first national marine park in Thailand (Figure 1). Khao Sam Roi Yot means the Mountain with three hundred peaks and refers to a series of limestone hills along the Gulf of Thailand, with the highest at 605 meters ASL. The northwest corner of the mountain range

is called Thung Sam Roi Yot and is mainly a freshwater marsh covering nearly 37% of the national park, making it the largest wetland area in Thailand, inside and outside the KSRY. The major agricultural products in the region include coconuts, pineapples, and mixed orchards, whereas rice is cultivated in smaller areas. Aquaculture and traditional shrimp and fish farms (Phosri et al., 2021). The climate in the study area can be divided into 3 seasons: winter between October - February with average temperatures between 18 and 25 degrees Celsius, summer between March-May with temperatures between 23 - 32 degrees Celsius, and the rainy season between June - September has temperatures between 20 - 30 degrees Celsius with an average rainfall of 800-1,200 mm/year. The wetlands of KSRY are registered as wetlands of international importance, number 2238 on the date. On January 8, 2008.

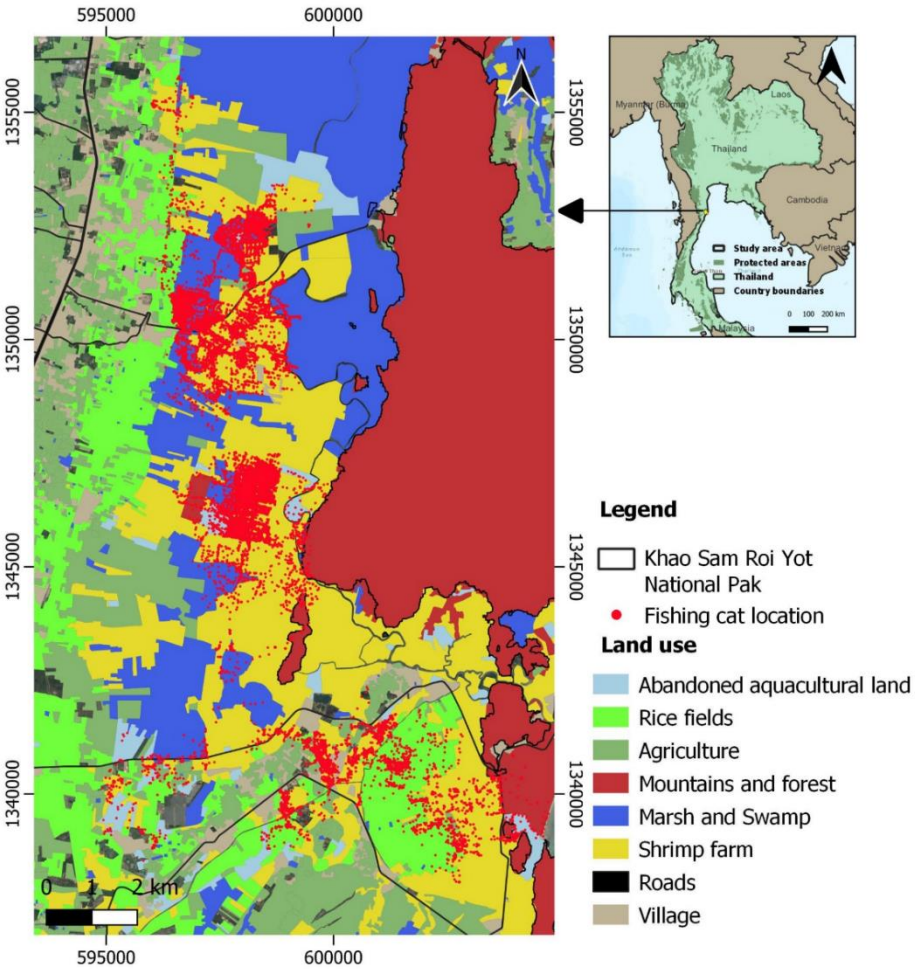

Figure 1. Map showing the location of the study area at the KSRY and all fishing cat data points conducted between June 2022 and February 2024.

Animal Capture and Collar

Animal capture was conducted with permission from the Department of National Parks Wildlife and Plant Conservation. Were captured using standardized cage-trapping methods (Serieys et al., 2023). Traps were primarily set in human-impacted areas, specifically around traditional shrimp and fishponds. Due to the heat, traps were closed during the days. Traps were thus checked every morning, as well as during the late evening. Once captured, individuals were immobilized using tiletamine hydrochloride plus zolazepam hydrochloride (4 mg/kg, Zoletil®) and xylazine hydrochloride (0.3 mg/kg) by a veterinarian and the lead veterinarian further led the capture. During capture, animals were sexed, and the age class was estimated as adult or subadult based on tooth wear, animal size, and evidence of reproduction. Morphological measurements were taken (Patumrattanathan, 2015). This study employed satellite collars (GPS collars) from Jul 2022 to Nov 2022, specifically, Lotek Wildcell SLG GPS collars (Lotek Wireless Inc., Newmarket, ON, Canada) equipped with cotton spacers to ensure that the collars eventually fell off. GPS locations were collected every four hours and data were downloaded from Lotek's web interface or directly from recovered collars (n = 2). Due to the poor performance of the Lotek Iridium collars from April 2023 to February 2024, we used e-obs 1C-Light GPS and triaxial accelerometers UHF collars (e-obs GmbH, Oberhachinger, Gruenwald, Germany). Collars were programmed to collect GPS locations every 10 minutes when the cats were active and every 4 hours when the cats were at rest. The e-obs collars were fitted with a cotton spacer to ensure a collar drop-off within one year. The collar weighs no more than 3% of the animal's body weight (Kenward, 2000; Ratnayaka et al., 2022). Detailed information on the fishing cats can be found in Table 1.

Data Analysis

Home range size

The home ranges of fishing cats were estimated using an autocorrelated kernel density estimator (AKDE) method, which involved applying the continuous-time movement modeling (ctmm) 1.2.0 package (Fleming & Calabrese, 2017; Fleming et al., 2022) in R version 4.3.2 software (R. Core Team, 2022). calculated home ranges for individual fishing cats employing (50%

AKDE) contours as a means of defining the core area, (75% AKDE), utilization area, and (95% AKDE) contours to specify the designated surrounding home range(Hinton et al., 2021; Sukmasuang et al., 2020; Prayoon et al., 2024).

Factors affecting the appearance

We used step selection functions (SSF) to investigate factors affecting the appearance. These were used to assess the factors affecting the appearance of the fishing cats within their home ranges. This method compares the available habitat features with selected locations and identifies the key factors influencing appearance and movement patterns using the animal movement tools (AMT) package (Avgar et al., 2016; 2017; Fieberg et al., 2021; Elie & Eric, 2018), and R version 4.3.2 (R Core Team, 2022). The factors affecting the appearance of the fishing cats' model were assessed using nine variables (Table 1) to explain the factors affecting habitat selection by fishing cats.

Table 1. Environmental variables for assessing the factors affecting the appearance of the fishing cats

Variable	Description	Source
Elevation	Extract and load data from Google Earth engine	https://earthengine.google.com/
Slope	Extract and load data from Google Earth engine	
NDVI	Extract and load data from Google Earth engine	
Distance to road	Euclidean distance to the major and minor road	Royal Thai Survey Department, Thailand
Distance to villages	Euclidean distance to the villages	Land Development Department, Thailand
Distance to marsh and swamp	Euclidean distance to the marsh and swamp	
Distance to aquaculture	Euclidean distance to the shrimp and fish farm	
Distance to abandoned aquaculture	Euclidean distance to abandoned aquaculture	

Results

The study captured and tagged with satellite collar 12 adult fishing cats (5 adult males and 7 adult females). This study used two collar companies: Lotek 3 and E-obs 9. The dataset included 15,461 locations for all fishing cats, covering all sexes (6,209 males and 9,252 females). Further

details on the fishing cat characteristics, capture data, and telemetry locations are provided in Table 2.

Table 2. Detailed information on the 12 adult fishing cats around the KSRYWL, Thailand.

Fishing cat ID	Weight (kg.)	Length(mm)				Collar Company	Number of telemetry location	Telemetry period
		Head and body	Tail	Neck	Chest			
Female								
FFC01	8.25	735	220	255	400	Lotek	196	20 Jul 2022–16 Nov 2022
FFC02	8.82	720	240	285	420	Lotek	119	08 Aug 2022–16 Sep 2022
FFC04	8.06	740	240	275	386	E-obs	2486	01 May 2023–21 Sep 2023
FFC05	9.56	792	255	280	410	E-obs	1959	21 Jun 2023–27 Sep 2023
FFC06	8.25	770	260	265	389	E-obs	842	21 Apr 2023–11 Jun 2023
FFC08	10.06	765	282	290	432	E-obs	1807	23 Nov 2023–27 Feb 2024
FFC10	7.62	730	310	260	380	E-obs	1843	18 Nov 2023–27 Feb 2024
Average	8.7	750.3	258.1	272.9	402.4	Total	9252	
Male								
MFC03	6.23	680	305	225	369	E-obs	1632	23 Aug 2023-3–02 Nov 2023
MFC07	14.92	850	345	315	470	E-obs	1922	22 Jun 2023–10 Nov 2023
MFC09	11.5	823	282	315	446	Lotek	208	26 Jun 2022–11 Aug 2022
MFC11	12.36	865	312	325	464	E-obs	2066	30 May 2023–25 Sep 2023
MFC12	13.65	765	320	360	500	E-obs	381	20 Nov 2023–13 Dec 2023
Average	11.7	796.6	312.8	308.0	449.8	Total	6209	

Home range estimation

Home range characteristics obtained for each fishing cat are shown in Figure 2. Each map shows the (50%AKDE) core area, (75%AKDE) utilization area, and (95%AKDE) home range area of each fishing cat. Male individuals' average estimated home range area was 6.29 km^2 (SD ±2.85; range: 3.40 – 9.69 km^2). The utilization area averaged 2.91 km^2 (SD ±1.55), while the core area averaged 1.29 km^2 (SD ±0.64). Female individuals exhibited a smaller average estimated home range area of 2.83 km^2 (SD ±1.22; range: 1.36 – 5.25 km^2). The utilization area for females was 1.51 km^2 (SD ±0.69) on average, with a core area averaging at 0.73 km^2 (SD ±0.33) in Table 2. The home ranges of fishing cats are shown in Table 3. Variograms, which depict the spatial autocorrelation of data points (Figure 2), show all 12 fishing cats using the AKDE method individually.

Table 3. Estimated 95, 75, and 50 percentile autocorrelated kernel density estimation (AKDE) around the KSRYWL, Thailand

Fishing cat ID	No. of locations	95% AKDE (Area km^2)			75% AKDE (Area km^2)	50%AKDE (Area km^2)
		low	est.	high		
Female						
FFC01	196	2.36	3.21	4.20	1.65	0.79
FFC02	119	3.85	5.25	6.86	2.87	1.37
FFC04	2486	2.17	2.96	3.87	1.60	0.75
FFC05	1959	0.99	1.36	1.77	0.65	0.30
FFC06	842	1.86	2.53	3.31	1.39	0.67
FFC08	1807	1.69	2.30	3.01	1.17	0.54
FFC10	1843	1.59	2.17	2.83	1.21	0.66
Total	9252	2.07	2.83	3.69	1.51	0.73
Male						
MFC03	1632	7.11	9.69	12.66	4.63	1.89
MFC07	1922	4.45	6.06	7.92	2.24	0.89
MFC09	208	2.49	3.40	4.45	1.76	0.92
MFC11	2066	2.69	3.66	4.79	1.39	0.67
MFC12	381	6.35	8.66	11.32	4.53	2.06
Total	6209	4.62	6.29	8.23	2.91	1.29

Table 4. Average estimated 95, 75, and 50 percentile autocorrelated kernel density estimation (AKDE) in KSRYWL, Thailand.

Fishing cat	Area (km^2)		
	Home range area (95%AKDE)	Utilization area (75%AKDE)	Core area (50%AKDE)
Average area			
Female	2.83	1.51	0.73
	[min 1.36; max 5.25]	[min 0.65; max 2.87]	[min 0.30; max 1.37]
Male	6.29	2.91	1.29
	[min 3.40; max 9.69]	[min 1.39; max 4.63]	[min 0.67; max 1.89]

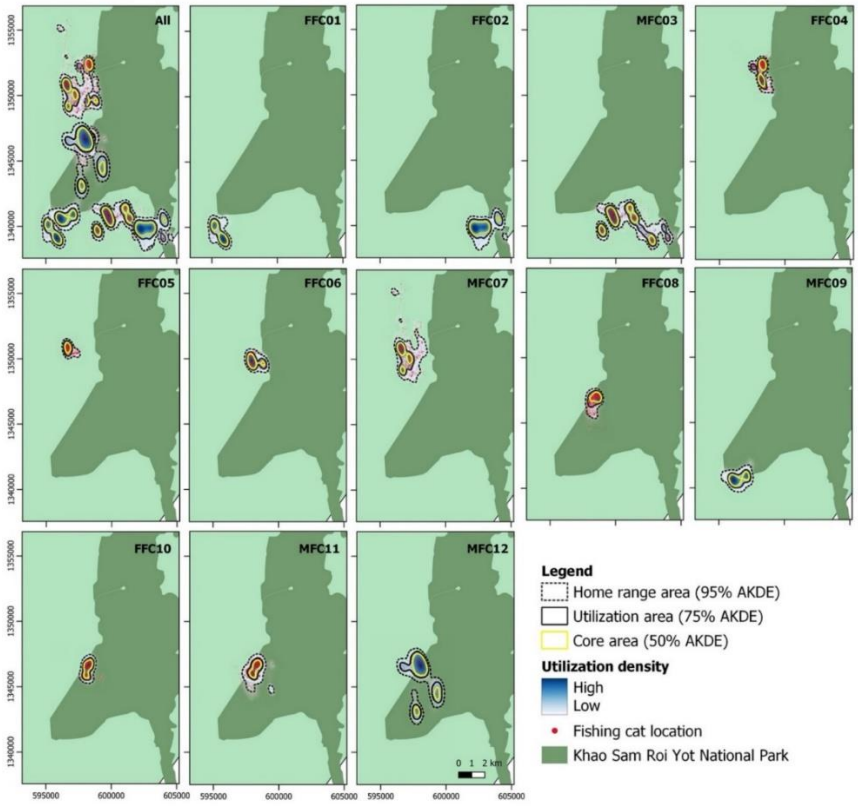

Figure 2. Home range of 12 collar fishing cat individuals in the KSRY, Thailand, from 2022 to 2024. Using an autocorrelated kernel density estimator (AKDE) the figure shows three confidence levels (95%, 75%, and 50%). The study of seven fishing cat females (FFC01, FFC02, FFC04, FFC05, FFC06, FFC08, and FFC10) and five fishing cat males (MFC03, MFC07, MFC09, MFC11, and MFC12).

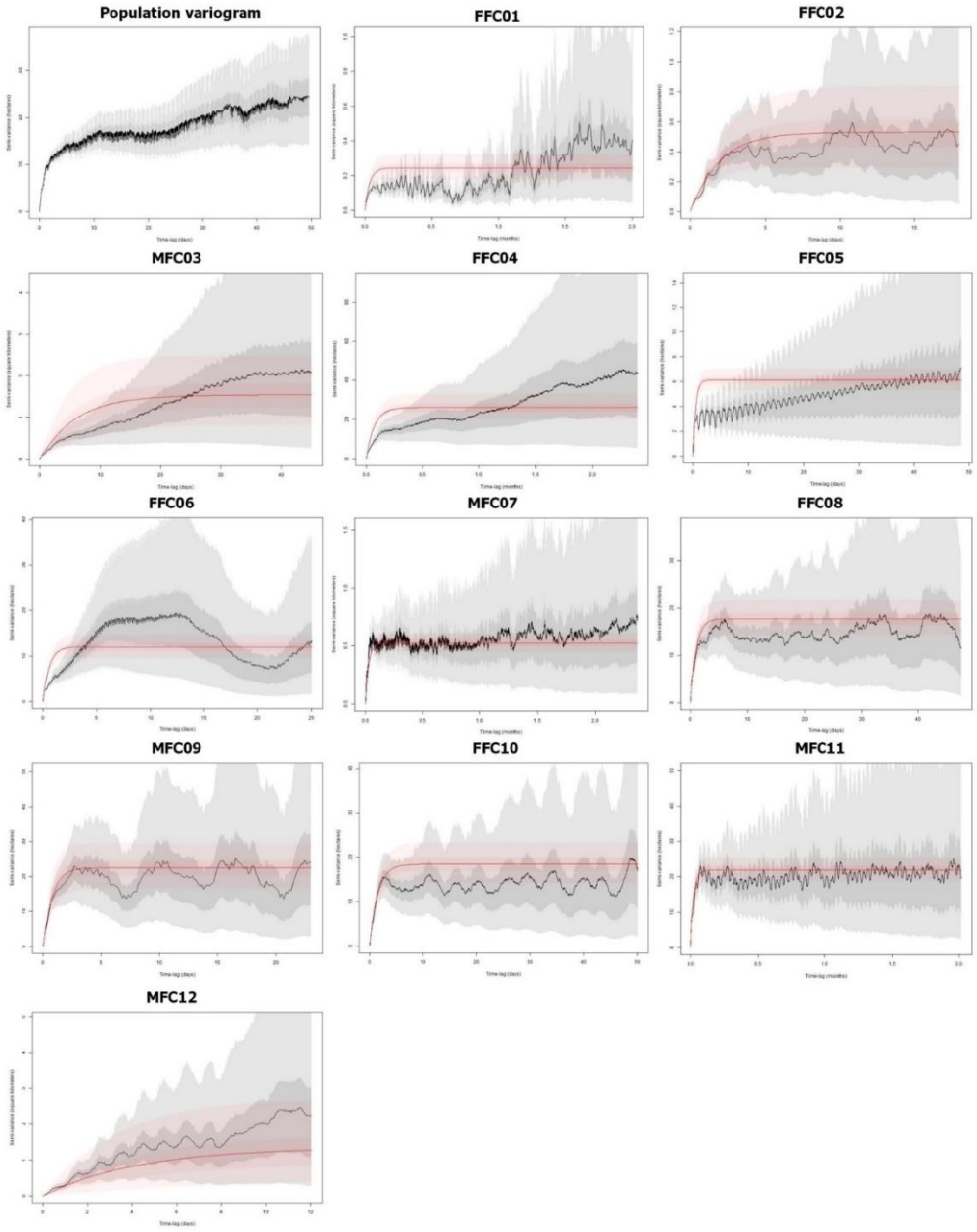

Figure 3. Variograms of 12 collared fishing cats between semi-variance and time lag. Fishing cats comprise seven females (FFC01; FFC02; FFC04, FFC05; FFC06; FFC08; FFC10) and five males (MFC03, MFC07, MFC09, MFC11; MFC12). The shading represents the 95% confidence intervals.

Factors affecting

The factors affecting the appearance of fishing cats were investigated using step-selection functions (SSF) with topographic variables, including elevation, slope, and normalized difference vegetation index (NDVI). Human-related variables included distance to roads, villages, marshes, swamps, aquaculture, and abandoned aquaculture. The results of habitat selection for female and male individuals (Table 5).

Discussion

Home range estimation

This study found that the size of the habitat area of males (6.29 km^2) was approximately twice as large as that of females (2.83 km^2). The results of this study were in the same direction as the results of past studies in the area where it was found that the habitat area of males was larger than that of female fishing cats (Cutter, 2015; Patumrattanathan, 2015). However, what is different from the results of past studies is that the habitat area size obtained from this study was larger than that of female fishing cats (Cutter, 2015; Patumrattanathan, 2015). Patumrattanathan (2015) more than 1 time (2.91 km^2 for males and 1.51 km^2 for females). It is also similar to the results of the study conducted by Cutter (2015), who investigated the home range size and core area results using the Fixed Kernel method at 95% and 50% were 4.01–13.53 km^2 (FK95%) and core area 0.9–3.05 km2 (FK50%). The female home range size is 1.98–6.78 km2, and the core area is 0.51–1.36 km^2 (Cutter, 2015). These differences are due to differences in the equipment and analysis methods used in the study. The results of this study are larger than those of Ratnayaka et al. (2024), who reported that the mean (±SD) LoCoH home range size for all three resident fishing cats was 1.17±0.74 km2. The mean (±SD) LoCoH core area was 0.35±0.09 km^2. The mean (±SD) KDE home range was 2.63±1.04 km^2, and the mean (±SD) KDE core area was 0.53±0.21 km^2 conducted in Colombo, Sri Lanka, which is similar to the home range sizes of female fishing cats in this study. The differences in home range size between the sexes are due to variations in resource utilization reflecting the cost-benefit trade-offs in behavioral decisions (Cattarino et al., 2016). Considering the home range distribution, we cannot conclude the relationships between males and females in terms of home range overlap that reflects kinship, mating, and pup-rearing behavior in fishing cats. This should be followed up with further studies. However, the difference in size between male and female home ranges corresponds with their polygamous mating system, where one male breeds with several females (Hedmark et al., 2007).

Table 5. Coefficients of the fitted step-selection function of female and male fishing cats and data combined for factors affecting the appearance around the KSRYWL, Thailand

Factors	Coefficient	Exp (coef)	SE (coef)	Z	P-value
All fishing cat					
Topographic variable					
Elevation	-0.058852	0.942846	0.012693	-4.637	3.54e-06 ***
Slope	0.030952	1.031436	0.00992	3.12	0.00181 **
NDVI	0.184192	1.202247	0.009003	20.459	< 2e-16 ***
Human related variables					
Distance to road	-0.008498	0.991538	0.009418	-0.902	0.3669
Distance to villages	-0.024521	0.975777	0.012503	-1.961	0.04986 *
Distance to marsh and swamp	-0.005857	0.99416	0.008946	-0.655	0.51263
Distance to aquaculture	-0.031134	0.969346	0.011827	-2.632	0.00848 **
Distance to abandoned aquaculture	-0.029997	0.970448	0.009767	-3.071	0.00213 **
Female					
Topographic variable					
Elevation	0.02711	1.02748	0.01061	2.554	0.01064 *
Slope	-0.04288	0.95803	0.01352	-3.171	0.00152 **
NDVI	0.15984	1.17332	0.0117	13.665	< 2e-16 ***
Human related variables					
Distance to road	-0.02769	0.97269	0.0163	-1.699	0.0894
Distance to villages	-0.02002	0.98018	0.02008	-0.997	0.3188
Distance to marsh and swamp	-0.01379	0.9863	0.01773	-0.778	0.4367
Distance to aquaculture	-0.03667	0.964	0.02259	-1.623	0.1045
Distance to abandoned aquaculture	-0.03458	0.96601	0.01564	-2.211	0.0271 *
Male					
Topographic variable					
Elevation	0.05467	1.05619	0.01226	4.459	8.22e-06 ***
Slope	-0.06972	0.93265	0.01966	-3.546	0.000391 ***
NDVI	0.21733	1.24275	0.01422	15.286	< 2e-16 ***
Human related variables					
Distance to road	0.01029	1.01034	0.01651	0.623	0.53307
Distance to villages	-0.03607	0.96458	0.01867	-1.932	0.05341
Distance to marsh and swamp	-0.0124	0.98768	0.01384	-0.896	0.37028
Distance to aquaculture	-0.04117	0.95966	0.01591	-2.587	0.00968 **
Distance to abandoned aquaculture	-0.03312	0.96742	0.01448	-2.287	0.02217 *

The asterisk indicates the significance of the factor (P < 0.1, * P < 0.05, ** P < 0.01, and *** P < 0.001)

Factors affecting the appearance

Topographic variables

Elevation has a highly significant negative coefficient. This suggests that fishing cats tend to avoid areas with higher elevations, possibly because of associated factors, such as limited access to water sources and increased competition. The slope exhibited a significantly positive coefficient, indicating that fishing cats prefer habitats with steeper slopes. Steeper slopes may offer better cover, refugee, or hunting opportunities for fishing cats, aligning with their habitat preferences and ecological requirements. The NDVI showed an extremely significant positive coefficient. This indicated a strong preference for fishing cats in areas with higher vegetation density or greener landscapes. Such areas will likely provide suitable habitat conditions including food resources, shelter, and protection from distractions.

Human-related variables

This study suggests that fishing cats exhibit adaptability and inhabit a diverse range of habitat types, including those subjected to disturbance. The coefficient of the distance to the road indicates that this relationship is not statistically significant. This suggests that the presence or proximity of roads does not significantly influence habitat selection by fishing cats. The coefficient of distance to villages was negative. Fishing cats tend to select habitats closer to villages, possibly due to factors such as prey availability near human settlements or adaptation to anthropogenic landscapes. The negative coefficients for distance to marsh and swamp were not statistically significant. This indicates that proximity to marshes and swamps did not influence fishing cat habitat selection in the study area. The coefficient of distance to aquaculture was negative. Fishing cats use areas close to aquaculture sites. This is because most of the area is aquaculture, a source of prey for fishing cats. The negative coefficient for the distance to aquaculture indicates that fishing cats select areas closer to active aquaculture sites. This implies that active aquaculture affects habitat selection by fishing cats, possibly because of prey availability linked to aquaculture activities. The negative coefficient for distance from abandoned aquaculture sites indicates that fishing cats select abandoned ones. This indicates that abandoned aquaculture affected the selection of habitats for fishing cats. This may be because of Low human interference factors disturbance and that natural prey can be found in the area.

Conclusion

This study offers new knowledge on home ranges and habitat selection around KSRY. Home range and utilization patterns of male and female individuals emphasize the importance of considering sex-specific behaviors and ecological requirements in wildlife research. The fishing cat habitat selection results were influenced by human-related variables, particularly proximity to villages, active aquaculture sites, and abandoned aquaculture sites. These findings provide insights into the impact of human activities on fishing cat habitats and highlight the importance of conservation and management efforts.

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