Journal Pre-proof

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PII: S2351-9894(21)00165-7

DOI: https://doi.org/10.1016/j.gecco.2021.e01615

Reference: GECCO1615

To appear in: *Global Ecology and Conservation*

Received date: 29 November 2020
Revised date: 30 March 2021
Accepted date: 28 April 2021

Please cite this article as: Kitipat Phosri, Naruemon Tantipisanuh, Wanlop Chutipong, Meredith L. Gore, Anthony J. Giordano and Dusit Ngoprasert, Fishing cats in an anthropogenic landscape: a multi-method assessment of local population status and threats, *Global Ecology and Conservation,* (2020) doi:https://doi.org/10.1016/j.gecco.2021.e01615

Fishing cats in an anthropogenic landscape: a multi-method assessment of local population status and threats

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Abstract

Fishing cat populations appear to have declined significantly in recent years due to the loss and fragmentation of inland and coastal wetland habitats. Moreover, there are still large gaps in data on population and density estimates, and threat evaluation, which are vital for conservation assessments. This research aimed to help fill these critical knowledge gaps. Our study is the first density estimate for fishing cat from mainland Southeast Asia. We conducted a camera-trap survey and used a spatially-explicit capture-recapture analytical framework to estimate the abundance of fishing cats in and around Khao Sam Roi Yot area (KSRY), which hosts an isolated, threatened population of the felid in Thailand. We also conducted interviews among adjacent communities to better understand local perspectives toward fishing cats, conflict with local people, and as a consequence of both, anthropogenic threats to the population. Over 6,966 trap-days, we identified at least 33 individual adult cats and based on our top model (g0~bk, σ~h2), we estimated fishing cat density to be 18 ± SE 6 individuals/100 km^2 (95% CI 10 – 33). Among 80 interviewees, we recorded 25 incidents of conflict, most relating to raids on poultry (n=18) and damage to fishing gear in pursuit of fish (n=5). Land use type, land use change, and human activity, did not significantly affect fishing cat density and movements. Our findings further suggest that a proposed tax policy governing land use may force landowners to convert suitable fishing cat habitat to unsuitable areas, resulting in the loss of up to 30% of existing suitable habitat from our study area. We also found that local communities would support either an exemption for landowners not wishing to develop suitable fishing cat habitat, and/or an additional policies that incentivize the maintenance and/or preservation of areas suitable for fishing cats. Finally, we conclude that the official presence of park officers in communities beyond the protected area would be beneficial, as would the implementation of public outreach programming to mitigate negative attitudes toward fishing cats, and provide recommendations on strategies for coexisting with them.

Keywords: camera-trapping, human dimensions, interviews, *Prionailurus viverrinus*, spatially explicit capture-recapture, Thailand

บทคัดย่อ

ประชากรเสือปลามีการลดลงอย่างมีนัยสำคัญ เนื่องจากการสูญเสียและการแบ่งแยกของพื้นที่ชุ่มน้ำภายในแผ่นดินและตามแนวชายฝั่งทะเล การขาดการประเมินประชากรและความหนาแน่นรวมไปถึงการประเมินภัยคุกคาม ซึ่งเป็นสิ่งจำเป็นจึงเป็นช่องว่างในการจัดการอนุรักษ์เสือปลา งานวิจัยนี้ได้ทำการติดตั้งกล้องดักถ่ายภาพสัตว์ป่าและใช้การวิเคราะห์แบบจำลองการจับและจับซ้ำเชิงพื้นที่ เพื่อประเมินความหนาแน่นของประชากรเสือปลาบริเวณพื้นที่ภายในและภายนอกรอบ ๆ อุทยานแห่งชาติเขาสามร้อยยอด ซึ่งเป็นกลุ่มประชากรเสือปลาที่โดดเดี่ยวและตกอยู่ในสภาวะถูกคุกคามของประเทศไทย พร้อมทั้งได้ทำการสัมภาษณ์ชาวบ้านในชุมชนที่อาศัยอยู่รอบ ๆ พื้นที่อุทยานฯ เพื่อทำความเข้าใจถึงทัศนคติของคนในท้องถิ่นที่มีต่อเสือปลา รวมไปถึงสาเหตุที่สร้างความขัดแย้งระหว่างคนกับเสือปลา จากการตั้งกล้องดักถ่ายภาพทั้งหมด 6,966 วันสำรวจ สามารถจำแนกเสือปลาจากลวดลายได้อย่างน้อย 33 ตัว และจากการวิเคราะห์ข้อมูลพบว่าโมเดลที่ดีที่สุดคือ (g0~bk, σ~h2) สามารถประเมินความหนาแน่นของประชากรเสือปลา เท่ากับ 18 ตัวต่อ 100 ตารางกิโลเมตร (95% CI 10–33 ตัวต่อ 100 ตารางกิโลเมตร) ในส่วนของการสำรวจด้วยแบบสอบถาม ในกลุ่มผู้ให้สัมภาษณ์จำนวน 80 คน พบว่ามี 25 เหตุการณ์ที่ประสบปัญหาความขัดแย้งระหว่างคนกับเสือปลา แต่ปัญหาที่พบบ่อยเกิดจากการที่เสือปลาเข้ามากินไก่หรือเป็ด (18 เหตุการณ์) และความเสียหายจากการเข้าทำลายลอบดักปลา (5 เหตุการณ์) อย่างไรก็ตามพบว่าประเภทการใช้ประโยชน์ที่ดินหรือการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินรวมไปถึงกิจกรรมจากมนุษย์ ไม่ส่งผลต่อความหนาแน่นและการเคลื่อนที่ของเสือปลา กระนั้นสิ่งที่อาจจะส่งผลกระทบในอนาคตคือนโยบายการจัดเก็บภาษีรูปแบบใหม่ของรัฐบาล อาจเป็นแรงจูงใจให้เจ้าของที่ดินทำการเปลี่ยนแปลงการใช้ประโยชน์ที่ดินถึงร้อยละ 30 ของพื้นที่ที่เสือปลาสามารถอยู่อาศัยได้ เพื่อป้องกันการเปลี่ยนแปลงพื้นที่อยู่อาศัยของเสือปลาในอนาคต รัฐบาลควรมีนโยบายในการยกเว้นการจัดเก็บภาษีพื้นที่เพื่อการอนุรักษ์

สำหรับเจ้าของที่ดินที่ไม่ต้องการพัฒนาพื้นที่
เพื่อใช้เป็นที่อยู่อาศัยของเสือปลาหรือเพิ่มแรงจูงใจต่อเจ้าของที่ดินด้วยการอนุรักษ์การใช้ประโยชน์ที่ดินในลักษณะดั้งเดิม ส่วนการเพิ่มการลาดตระเวนของเจ้าหน้าที่บริเวณรอบ ๆ อุทยานฯ หรือพื้นที่ชุมชนนั้น
จะมีส่วนช่วยในการเฝ้าระวังการล่าหรือฆ่าเสือปลา
ยิ่งไปกว่านั้นการเผยแพร่ประชาสัมพันธ์โดยชุมชนมีส่วนร่วม
จะช่วยลดทัศนคติเชิงลบและให้คำแนะนำการอยู่ร่วมกับเสือปลาให้แก่คนในชุมชนได้

คำสำคัญ: กล้องดักถ่ายภาพสัตว์ป่า การสัมภาษณ์ ทัศนคติของคนต่อสัตว์ป่า

แบบจำลองการจับและจับซ้ำเชิงพื้นที่ ประเทศไทย เสือปลา

Introduction

Fishing cats (*Prionailurus viverrinus*) are widely distributed among coastal and inland wetlands across South and Southeast Asia (Mukherjee et al., 2016). Previously categorized as ‘Endangered’ by the International Union for Conservation of Nature (IUCN) in 2008 (Mukherjee et al., 2010), they were reclassified as ‘Vulnerable’ due to the perceived reduced severity in population declines since the previous assessment, and improved overall collective knowledge of the distribution of fishing cats (Mukherjee et al., 2016). Despite “downlisting”, local populations in many areas are suspected to have declined largely due to expanding human activities in coastal wetlands and estuaries – some of the most suitable habitats for fishing cats (Appel and Duckworth, 2016). The continued conversion of these natural habitats has reduced and isolated populations into small patches. In addition, conflicts with people pose recurring challenges to their conservation. Fishing cats are still illegally killed both in retaliation for depredation of poultry, fish, and other livestock, and to a lesser degree for consumption (Cutter, 2015;

Mukherjee et al., 2016; Thaung et al., 2018). These threats are thought to have caused localized extinctions in some regions (Mukherjee et al., 2016).

A better understanding of fishing cat population dynamics, potential susceptibility to anthropogenic threats, and local community attitudes toward the species, are important elements to successful and effective wildlife management (Chapron et al., 2014; Ali et al., 2018). Capture–recapture sampling using camera-traps is an effective technique to estimate the population density of cryptic animals with unique markings, particularly some species of felid (Karanth, 1995; Brodie and Giordano, 2013). Similarly, interview-based surveys are a widely accepted method in social science; they allow researchers to evaluate local perceptions, and collect information on potential or existing anthropogenic threats to the conservation or restoration of a population or species (Gore et al., 2013; Kahler et al., 2013; Young et al., 2018a; LeClerq et al., 2019; Greenspan et al. 2020; Ullah et al., 2020). To date, most investigations of fishing cats have mainly focused on their basic ecology and distribution (Mukherjee et al., 2016). For example, there are four recent studies on fishing cats in South Asia (Nair, 2012; Malla, 2016; Mishra, 2016; Das et al., 2017), and a few more in Southeast Asia (Cutter, 2015; Pathumratanathan, 2015; Thaung et al., 2018, Lin and Platt, 2019). However, these studies have not explicitly assessed critical threats to local fishing cat populations, which are essential component for species conservation. Conversely, studies of population status and of threats to those populations, have the capacity to help fill knowledge gaps for decision makers, and facilitate strategic planning and the allocation of adequate resources.

In Thailand, fishing cats have been documented in only a few inland and coastal wetlands (Chutipong et al., 2019). One of these is Khao Sam Roi Yot National Park (KSRY) and its adjacent habitats, an important national stronghold for the species in the country (Chutipong et al., 2019). Over the past four decades, KSRY wetlands have been converted to commercial aquaculture enterprises and human settlements, particularly along the park boundary (Huitric et al., 2002; Barbier and Cox, 2004). This has accelerated the shrinking and disappearance of regional habitat for fishing cats, and led to more frequent and intensive conflicts with people over poultry (*e.g.*, attacks on free-ranging chicken, in chicken or duck farms, etc.) and farmed fish (*e.g.*, depredation of animals, destruction of equipment and facilities, harassment of animals). The resulting conflicts have consequentially led to more negative attitudes toward fishing cats, and illegal retaliatory killings (Cutter, 2015). A previous radio-telemetry study over two years (2009-2010) in one area adjacent to KSRY, suggested that mortality of fishing cats is very high (69%, n = 16 cats). Nearly half of these (five individuals) were verifiably due to illegal killing, whereas the remainder (six individuals) were due to unknown causes that may have also included illegal retribution (Cutter, 2015). A better understanding of attitudes and prevalence of conflict among human communities could more effectively facilitate the deployment of mitigation strategies, and complement ecological data about the local fishing cat population (Ali et al., 2018).

Our study aimed to (1) estimate the density and size of the local fishing cat population both inside and outside KSRY, (2) assess local attitudes perceived threats toward fishing cats, and (3) synergize insights within the context of potential remedies and solutions. We hypothesized that anthropogenic land use patterns and changes have affected the density of fishing cats, and that population density and movements would be higher and range further respectively, across areas with relatively lower human disturbance compared to more adversely impacted areas.

Methods

Study Area

Khao Sam Roi Yot National Park (12°10′57″N 99°56′54″E, 98 km^2) is located in southwestern Thailand (Fig. 1). It harbors diverse wetland and forest ecosystems (*e.g.*, salt pans, cultivated areas, mudflats, grassland and shrubs, mangrove forests, sand beaches), and limestone ridges that are part of the Tenasserim Range (Department of National Parks, Wildlife and Plant Conservation, 2015). It also includes large freshwater marshes (37 km^2), a portion of which (~18 km^2) was declared a Ramsar wetland site in 2008 (Ramsar, 2015). The dry season ranges from December to May (average of ~54 mm rainfall/month), while the rainy season is from June to November (average of ~143 mm rainfall/month) (Thai Meteorological Department, 2013). Our effective sampling area (~336 km^2) encompassed habitat both inside and outside KSRY. Major agricultural production in the region includes coconut, pineapple, and mixed orchards, whereas rice is cultivated in smaller areas. Aquaculture and traditional shrimp or fish farms (*i.e.*, ponds not covered by plastic sheets, and still with some vegetative cover; Fig. 2) however, are believed to be the main sources of livelihood and local income in the area (Cutter, 2015; Pathumratanathan, 2015).

Land Use Type and Land Use Change

Based on our own field surveys and satellite images available to us in Google Earth, we updated a 2016 land use map (Land Development Department, Thailand) to produce a more current land use map (circa 2018). We used this map to classify five major land use types: (1) traditional aquaculture pond, (2) agriculture, (3) abandoned areas, (4) natural forest, and (5) unsuitable areas (Table 1). To quantify land use change, land use types were also grouped into two broad categories: (1) suitable, and (2) unsuitable areas for fishing cats. We defined suitable areas as any that cats can utilize to some extent, including traditional aquaculture ponds, agricultural land, abandoned areas, and natural forest. In contrast, we defined unsuitable areas as those that cannot be utilized, or are subject to a high degree of human disturbance. To characterize habitat loss, we calculated change of three land use types (traditional aquaculture ponds, agriculture, abandoned areas) into unsuitable areas, and overall change of suitable to unsuitable areas (Table 1). Although there is evidence that fishing cats can use areas with high human impact, human settlement was classified as unsuitable due to the high mortality previously documented in KSRY (Cutter, 2015).

Local Perspectives and Potential Threats

To gather data on potential threats to fishing cat survival, including land use change, retaliatory persecutions, and hunting, we conducted structured interviews with local residents living adjacent to the park in June 2018. We overlaid the 2x2 km grids over the study area (n = 93 grids); based on Official Statistics Registration Systems (2010), we identified 25,169 households in our study area. We sampled at least 0.5% of all households by interviewing at least one to three persons we encountered in each grid. Before questionnaires were used, we ensured interviewees were of study area residents, and had lived in the area for at least the past 5 years, regardless of whether they held land titles.

Interviews took approximately 15–30 minutes each. Before each interview, we created comfortable conditions and a safe environment by introducing ourselves (*e.g.*, who we are, what are objectives were), describing the interview process (*e.g.*, what kind of questions will be asked, their right to not answer or stop the interview at any time, ensuring their anonymity), and stressing that no one will receive any legal penalty for sharing information (Davis et al., 2019; Nuno and John, 2015). We did not use the voice recorder to avoid bias answering from interviewees. Instead, we used two people, one asking questions while another one taking note. At the beginning of each interview, we asked interviewees about the place where they usually spend time, and marked geographical coordinates using a GPS (if for example, that was the place where the interview was conducted), or located it on Google Maps late (*i.e*., if their land was not where the interview was conducted, we asked interviewees to explain the location of their places in detail). Interviewees were then asked whether they were a landowner, or just renting. If they confirmed they were a landowner, we then asked the questions in Section I for land use change. If not, we omitted this section. Questions in Section I addressed current land uses, plans to change or alter current land use activities within the next 5–10 years, and their motivations to change land use, if applicable.

Before continuing to Section II (Interactions with fishing cats) and Section III (Hunting and Persecution) of questionnaires, interviewees were asked to describe the physical characteristics of fishing cats (*e.g.*, head, body, legs, pelage pattern, tail), the habitats where fishing cats are found, and correctly choose an image of a fishing cat amongst other four sympatric carnivore species, to confirm that interviewees were truly familiar with fishing cats. Other images in the set of photographs included: Leopard Cat (*P. bengalensis*), Large Indian Civet (*Viverra zibetha*), Large-spotted Civet (*V. megaspila*) and Small Indian Civet (*Viverricula indica*). Only interviewees who both accurately described the characteristics and habitats of fishing cat, and selected the correct image, were considered “qualified” and thus included in the analyses presented herein.

Section II (Interactions with Fishing Cats) of the questionnaire addressed whether interviewees had (1) previously experienced conflict with fishing cats, (2) what approaches they took to mitigate conflict, (3) what outcomes they achieved if known or ongoing, and (4) any alternative solutions they may have considered. Section III (Hunting and Persecution) assessed (1) the potential causes of hunting or killing in the past and present, (2) inquired about local attitudes toward fishing cats, and (3) assessed the reasons for peoples' existing attitudes. For both sections, we asked interviewees to provide information from only from those areas where they usually spend time (*e.g.*, the GPS coordinates taken at the beginning of the interview), not places they visited infrequently.

This study has been approved by human ethics committee of the King Mongkut's University of Technology Thonburi (KMUTT-IRB-2018/0322/111). We also received verbal consent from participants to use their data for publication. The complete survey instrument is available by request from the lead author (Appendix I).

Camera-trapping

To assess our study area for its potential to evaluate fishing cat population status using camera-traps, we first conducted a preliminary survey of fishing cat sign (e.g., tracks, scats) between December 2017 and May 2018 (Fig. 1). Camera-traps were established in locations where fishing cat evidence (*i.e.*, footprint, scat) was present, or in areas considered highly suitable for fishing cat occurrence (*e.g.*, tree and/or ground cover) and thus a high likelihood of getting photo. Based on these preliminary surveys, we established 50 camera-trap stations (15 stations were installed inside, whereas 35 stations were placed on private land outside the KSRY; Fig. 1) across approximately 225 km^2 (camera-trapping polygon), and conducted our sampling between November 2018 and April 2019. Camera-trap stations were spaced an average of 2.2 km apart based on the spatial scale of the movement parameter (sigma, σ) calculated from our preliminary results (Appendix II and Appendix III). All camera-trap stations consisted of a pair of camera traps (SCOUTGUARD camera – model SG565FV, with the incandescent white flash) operating 24 hours/day, with each of the two cameras spaced 6 m apart and facing directly opposite directions, in order to maximize detection of both flanks and thus facilitate identification of individual animals. Cameras were set to photograph mode only to record a single still photo, with a minimum interval of 30 seconds before re-triggering. To increase detection rates and improve the precision of density estimates (*e.g.*, Braczkowski et al., 2016) at each location, we used a 490 ml tin can filled with fish oil (scent lure) buried at a central distance between each of the two opposite-facing camera-traps. Camera-trapping effort was then calculated as the sum total of trap-days for all stations for the duration they were functional.

Analysis of Perspectives and Threats

We analyzed descriptive statistics for all sections of our questionnaire surveys, and then mapped the spatial distribution patterns of reported conflict incidents. We used the 'Spatial Autocorrelation (Global Morans I)' toolbox in ArcGIS 10.6 to assess patterns of conflict occurrence, and performed a chi-square test to evaluate for attitudinal differences between landowners and renters. We created an index of "point scores" from each respondent's interview based on one of four categories, each reflecting hunting/persecution intensity from past to present. These scores were as follows: 0 = no hunting or persecution in the area; 1 = hunting or persecution occurred in the past five years, but not presently; 2 = hunting and/or persecution occurred in the past, and some occurs presently; and 3 = hunting and persecution have continued unabated from past to present. We then used these indices to spatially interpolate a threat level map using the 'Inverse Distance Weighted' toolbox in ArcGIS (Setianto and Triandini, 2013).

Density Estimation

We distinguished individual cats recorded on photographs based on their unique patterns of stripes and spots on their body, limbs, neck, and face (Fig. 3). Several of the authors examined all photographs and re-checked a subset for individual identification, from which a final capture history for each individual was produced. For photographs that captured only one flank (left or right), individual fishing cats were distinguished for that flank; the minimum number of individuals captured for each side was then compared and added to the number distinguished for individuals identified using both flanks. We determined the sex of an individual adult based on the presence or absence of observable testicles, and created a unique capture-history for each individual. We assigned each survey occasion equal to one day.

To estimate fishing cat population density, we used a spatially explicit capture–recapture analytical framework in package 'secr' (Efford, 2019a) of Program R (R Core Team, 2019). To mask areas outside of our trapping area, we created 10 km buffers around the boundary of each camera-trapping polygon that consisted of our outermost camera-trap stations (Fig. 1). To further evaluate the role of buffer width and mask spacing on density estimates, we used the 'esa.plot' and 'mask.check' functions in 'secr' to vary these parameters. All models were fitted using a full likelihood approach to estimate different capture probabilities (g0) and scales of movement (σ) for males and females (Sollmann et al., 2011), and then fitted using the half-normal function. To identify those factors affecting the scale of movement, three groups of covariates were included: (1) human-caused disturbances, (2) current land use type, and (3) land use change (Table 1). For human-caused disturbances, we examined three potentially suitable proxies: (1) distance to railway, (2) distance to main highway, and (3) threat level (index as determined from interviews). We also tested whether movements differed between males and females using finite mixture models (h2). Based on their impacts on wildlife from other studies (Lucas et al., 2017; Barrientos et al., 2019; Sidorovich et al., 2020), we hypothesized that human activities on the main road and railway (Fig. 1) would negatively affect fishing cat movement either due to noise or vibration, and/or as a physical barrier. We further assumed that different persecution threat levels may have affected cat movements from past to present, *i.e.*, fishing cats might actively avoid areas of higher threat intensity (Havmøller et al., 2019). We obtained road and railway shapefiles from our updated land use map, and calculated the distances from each camera-trap station to both railways and main highways (km) using the 'Euclidean Distance' toolbox in ArcGIS. The threat levels associated with each camera-trap station were extracted from the threat level map (see *Local Perspectives and Potential Threats*) using the 'Extract Values to Points' toolbox. To map current land use type and land use change, we established a 1-km buffer around each camera-trap station, which was based on the estimated spatial scale of movement (1.3 km) from our preliminary results, and then calculated the total area within each buffer (in km^2).

To estimate capture probability (g0), we assessed and incorporated the effects of cat behavioral responses, trapping effort, and human-caused disturbances. Behavioral response models related to capture probability included: (1) a learned response for all traps in the survey array (*b*); (2) a trap-specific behavioral response for all occasions after initial capture (persistent, *bk*); and (3) a trap-specific behavioral response only on the occasion immediately after initial capture (ephemeral, *Bk*). We compared model strength of evidence using AIC_c and relative AIC_c weight (Akaike, 1973; Burnham and Anderson, 2002). To identify the best estimates of density, we identified the top model with the lowest ΔAIC value and relative weight, and subsequently assessed the precision of each estimate using the coefficient of variation (CV) (Pollock et al., 1990).

To determine the importance and effects of land use type/area and threat prevalence to fishing cats, we computed the 95% probability density of each home range center using the "fxi.contour" function in the 'secr' module of Program R (R Core Team, 2019). This allowed us to estimate home range centers for all cats detected based on our best fitted model (Efford, 2019a). We then extracted the home range polygons for individual cats as a shapefile in ArcGIS, and superimposed them on current land use and threat level maps. For fishing cats with home ranges outside the national park, we also calculated the median distance, the standard deviation of mean distances between home range centers, and the closest distance to the national park boundary.

Results

Land Use Type and Change

Of our total study area (336 km^2), abandoned areas and agricultural lands nearly equally comprised the highest proportions by land use (90 and 87 km^2, respectively); these were followed by traditional aquaculture (58 km^2), "unsuitable area" (57 km^2), and natural forest (44 km^2; Fig. 4A). We determined that approximately 83% (279 km^2) of our total study area therefore was "suitable" to fishing cats, whereas 17% was not suitable. Based on these definitions, we also note that between 2016 and 2018, fishing cats lost approximately 2% (7 km^2) of suitable habitat within our study area (Table 2).

Local Perspectives and Potential Threats

We interviewed 113 respondents from 27 villages, of which 80% (76 males: 14 females) were landowners. Among landowners, 87% said they would not change their current land use practices, whereas 9% reported being open to changing them. Approximately 80% of landowners remarked they would not sell their land in the next five years (2019-2023), even if the price of their land increased significantly; approximately 17% reported being conditionally open to selling their land. Based on landowner answers, those who owned rice paddy fields, orchards, and other agricultural crops (e.g., pineapple plantations), which comprised at least 31 km^2 (>9%) of the entire study area, were most likely to sell their land. The two most common reasons for landowners to sell their land were (1) insufficient profits from their current land use type (33%), and (2) to pay off debts attributed to loans for agricultural investments (13%).

In total, 80 interviewees (71%) correctly described the characteristics and habitats of fishing cats, and accurately identified images they were presented with. Among these, 25 out of 80 interviewees (31%) reported 25 cases of conflict between people and fishing cats. Most cases related to raids on poultry (18 cases). Other incidents of conflict however included damage to fishing gear (5 cases), and fish depredation (2 cases). We should caveat that we were not able to further validate whether alleged conflict cases really involved fishing cats, as the cases occurred sometime within the past 5 years. We found that the spatial pattern of conflict locations was randomly distributed (Moran's Index = 0.75, z-score = 1.59, $p = 0.11$), suggesting that conflict frequency was not associated with specific areas. Interviewees believed effective solutions for mitigating conflict and preventing poultry loss included: (1) strengthening the fencing of the henhouse with nets or steel mesh (10%), (2) increasing surveillance intensity (5%), and (3) using dogs as deterrents (2.5%). However, based on our interview findings, locals still resorted to lethal retaliatory methods, including snaring/trapping, poison baits, and shooting.

The threat level map (Fig. 4B) we prepared based on respondent answers indicated that the majority of our study area (61% or 206 km^2) had been subjected to past hunting and/or persecution, but that those activities do not occur at present (Level 1). Approximately 29% of the total study area (96 km^2) consisted of parts where hunting and persecution occurred in the past and sometimes occurred recently (Level 2), whereas hunting and persecution have largely continued unabated from past to present (Level 3) across 9% (33 km^2) of the area. We determined only 0.01 km^2 (<1%) of the mapped area had been subjected to no hunting and/or persecution, at least as reported. Interestingly, the majority of interviewees (59%) appeared to have strong positive attitudes towards fishing cat due to its perceived rarity, and claimed that it deserved conservation attention; 30% were neutral in their feelings toward the cat, whereas 6% strongly disliked the cats due to prior conflicts they had experienced, and concerns regarding their own safety; 5% did not provide an answer. We found no difference in attitudes between landowners and "renters" (non-owners) toward fishing cats ($\chi^2 = 1.56$, df = 2, $p = 0.46$).

Density Estimation

We detected fishing cats at 21 of our camera-trap stations (42%) over 6,966 camera trap-days, seven of which were located inside the national park. Of the 625 images of fishing cats we obtained, we selected 576 images (92%) as suitable for identifying individual animals. Conversely, approximately 8% of images (49 images) were obscured, largely due to photographs of only part of an animal, and/or animals in images simply not positioned in a way that facilitated individual identification with confidence. In addition, we also camera trapped six other small carnivore species in our study site including Leopard Cat, Small Asian Mongoose (*Herpestes javanicus*), Ferret-badger (*Melogale sp.*), Large-spotted Civet, Small Indian Civet, and Common Palm Civet (*Paradoxurus hermaphroditus*).

We identified 33 adult cats in total (15 males, 15 females, and 3 of unknown sex) based on their individual characteristics and markings. Since the numbers of individuals identified from only one-flank photographs were equal, and the sex of those individuals was unknown, we combined identifications based on both flanks (31 cats) with those made from left flanks only (2 cats), for our capture histories and subsequent analyses. Our top model was the trap-specific behavioral response on capture probability, with movements differing between males and females (g0~bk, σ~h2); it received greater evidentiary support relative to all other models (AIC_c weight = 0.93; Table 3). When bk = 0, capture probability was 0.010 (95% CI = 0.005–0.021) but when bk = 1, it increased nine-fold (0.098, 95% CI = 0.075–0.125). Also, females moved significantly less than males overall (σ = 894 m, 95% CI = 598–1,335 m for females; σ = 1,771 m, 95% CI = 1,373–2,285 m for males). Based on this top model, we estimated fishing cat density (*D*) for our study area at *D* = 18 individuals/100 km^2 (95% CI = 10–33), with the CV = 31%. Our estimate of population size (*A*) therefore for our overall effective sampling area, was 66 individuals (95% CI = 37–121).

Home range polygons derived from the best fitted model encompassed a total area of approximately 234 km^2; we excluded 31 km^2 of this total area (indicated in white in Fig. 4B) as either outside our land use map, and excluded non-habitat areas (27 km^2). We determined that 24 cats lived outside KSRY, with home range centers an average distance of 2,203 m ± SD 1,264 m from the park boundary; in addition, nine cats lived mostly or entirely inside the park (820 m ± SD 610 m). Fishing cats used all five land use types, with abandoned areas representing the highest proportion of habitat used (53 km^2, 30%), followed by traditional aquaculture (47 km^2, 27%), agricultural lands (39 km^2, 22%), natural forest (27 km^2, 15%), and unsuitable areas (only human settlement;10 km^2, 6%).

Finally, we note that between 2016 and 2018, the amount of area unsuitable for use by fishing cats increased by 2.61 km^2. Agricultural expansion overwhelmingly represented the biggest reason for land use change (+2.45 km^2); yet this same land also had a higher relative probability of being sold or otherwise changing ownership. This was followed to a much lesser extent by an increase in traditional aquaculture (+0.16 km^2). Most of the total home range area for fishing cats (66%, 117 km^2) occurred inside low threat level areas (Level 1), whereas 31% of this area (54 km^2) constituted a moderate threat level for fishing cats, and likely will in the near future (Level 2). We considered only 5 km^2 (3%) of the area as falling within a high threat level zone (Level 3). Home range polygons did not overlap with areas considered to represent no threat (Level 0), probably because this area was too small (~100 m^2) as an artefact of how it was calculated (Fig. 4B).

Discussion

Population and Density

This study provides the first density estimate of a fishing cat population for Thailand, and thus also for all of mainland Southeast Asia. Fishing cats were attracted to camera-trap stations (g0~bk), and individual cats were more likely to revisit stations again after the first detection (*i.e.*, cats were "trap happy"). We interpreted this as evidence that the lure (*i.e.*, fish oil) we used to attract them to camera-trap stations was highly effective. In addition to revisiting stations several times, scent lures also invoked various other behaviors in front of the cameras, including cheek-rubbing, sniffing, and rolling, yielding sufficient high-quality photographs for individual identification as they have for other felids (Schlexer, 2008; Braczkowski and Watson, 2013). The differences in average estimated movement distance between male and female (σ~h2) fishing cats was consistent with findings for other felids (Machado et al., 2017; Mohamed et al., 2019). We found that land use type, rate of change, and human activity, did not have significant effects on fishing cat density and movement. Instead, cats appeared to utilize several types of land, including human settlements. Fishing cats were also more tolerant of less suitable habitat and disturbances, a conclusion perhaps best illustrated by the 34% overlap of home range polygons with areas of moderate to high threat levels (Fig. 4B).

Prior to this study, there were only four reported estimates of fishing cat population density, all originating from South Asia (Appendix IV). Due to the low precision of estimates (CV = 177%) from Malla (2016), whereas Mishra (2016) did not indicate the SE or CV of density estimated, and the use of single-flank only photo identifications by Nair (2012), we suggest direct comparisons with those studies are not warranted, as these stipulations can affect estimate reliability (Augustine et al., 2019). Das et al. (2017) achieved precision similar to ours (CV ~30%) in conducting a survey of mangrove forest (25 km^2) in Lothian Wildlife Sanctuary (LWS), India. Their estimates of density however were much higher (44 individuals/100 km^2), possibly due to greater homogeneity in habitat quality (*i.e.*, no mosaic of land use types), more intense threats adjacent to survey areas, or sampling artefacts associated with a smaller survey area than we had (~7.4%; 336 km^2 vs 25 km^2), all of which could have inflated estimates. Also, Das et al. (2017) reported on no incidents of conflict for LWS.

Local Perspectives and Potential Threats

There are several overarching factors involving land use type and change in our study area that can affect the survival of fishing cats, and are these are worth discussing further. The first is the development of aquaculture ponds (*e.g.*, shrimp farms for local consumption or export). Even if there is no net gain in this land use type in the years ahead, landowners could still intensify land use by moving from traditional operations to more commercial ones. For the latter, pond beds are covered by plastic sheets, water levels are deeper, and labor activity can be greater, potentially making these areas far less suitable for fishing cats (Fig. 2 left). Moreover, commercial operations can alter the local hydrology by diverting large volumes of water, degrading overall habitat quality. The second issue is a recent tax policy by the Thailand government (Land and Building Tax Act B.E. 2562., 2019), which might lead to extensive land conversion. Under this new policy for example, landowners would have to pay higher tax rates for land not in use or "abandoned" relative to more productive forms of utilization consistent with economic development. This could force landowners to develop areas otherwise suitable for fishing cats, in order to avoid incurring a financial penalty. If hypothetically this were to lead to the conversion of all abandoned areas, up to 53 km^2 or 30% of the area within our home range polygon could be lost. Third, the construction of a double-track railway is currently underway on the west side of the study area and thus, represents a new potential threat. This railway will be extended and fenced to prevent collisions with livestock (OTP, 2015; Jaensirisak et al., 2017) (Fig. 5), thereby dividing a large portion of suitable habitat for fishing cats, and potentially limiting their movement and gene flow across the area (Barrientos and de-Água, 2017; Jakes et al., 2018).

Based on participant interviews, the raiding of poultry, damage incurred to fishing gear, and depredation of fish from ponds, were the most frequent causes of human-fishing cat conflict that led to illegal retaliatory killings around KSRY. We note that these findings are consistent with those from other countries around fishing cat related conflict (Chowdhury et al., 2015; Mukherjee et al., 2016). Participants reported awareness of approaches known to prevent local poultry raiding, including strengthening hen house fences with nets and steel mesh, increasing surveillance of poultry, and using dogs as guards to deter fishing cats. Use of dogs however only has conservation value if they are vaccinated, sterilized (*i.e.*, spayed or neutered), and properly cared for by landowners/ managers; otherwise, there is a risk they may become direct or indirect threats to fishing cats and other species (Daszak et al., 2000; Young et al., 2018b). Additional research evaluating the efficacy of human-wildlife conflict mitigation strategies, would offer more insights into the socio-cultural, technical, or economic constraints potentially affecting more widespread adoption of these strategies.

Based on our interviews and interpolated threat map, illegal hunting did not occur across approximately 70% of the study area. Cutter (2015) however, recorded a high mortality rate (31%) for radio-collared fishing cats in the same region, all believed to be from illegal hunting, which suggests that killing of fishing cats is or was more extensive than our results portray, or that a substantial change has occurred between studies. That risk data informed by locals or experts do not perfectly overlap for our analysis is not surprising (Kahler et al. 2013). The difference between participant perceptions of risk, and technical risk assessments of illegal activity, may be explained by social desirability bias during interviews, or a tendency for interviewees to intentionally minimize the significance or frequency of conflict (*e.g.*, in fear of reprisal against themselves and/or their neighbors). In Thailand, fishing cats are protected under the Wildlife Preservation and Protection Act B.E. 2562 (2019), and their intentional killing is illegal regardless of where, when, or how the incident occurs. Some interviewees suggested that frequent patrolling of the area by officials can help reduce illegal hunting or persecution. Due to the number of park rangers relative to their areas of responsibility however, and the limited resources of their offices, it is not clear if such patrols could sufficiently deter illegal hunting of fishing cats. Additional research therefore could help build understanding.

Study Constraints and Limitations

We admit that despite our goals, the precision of our density estimate was still low (CV =31%) relative to the minimum threshold desired for future population monitoring (~20%; Pollock et al., 1990). Although we ran simulations based on preliminary survey data to identify the minimum number of trap-days that would yield a CV < 20%, in hindsight these may have been based on findings across too small of an area (10 km^2; Fig. 1, Appendix II). In addition, our early simulation did not account for sex-specific differences in detectability (Appendix III). Given these considerations however, the CV we obtained from our full survey was still higher than otherwise would be expected. In order to increase precision for future sampling, our simulation models will incorporate sex-based capture heterogeneity as a covariate, incorporate a longer sampling period (*i.e.*, greater number of camera-trap days), and explore different ratios of total captured to recaptured animals, the latter of which will also improve our models of detection probability for later sampling.

We also acknowledge that the data we obtained from our questionnaires may not reflect accurate rates of illegal killing of fishing cats, as participants may have been wary of retaliation or some penalty. This is despite that we tried to minimize such response biases by attempting to create a safe environment for interviewees, including not needing personal identifying information, and conveying that we were affiliated with a university and not a law enforcement or government agency. We also used projective questioning – *i.e.*, asking interviewees to describe what they have heard from other people, not necessarily their direct experiences (Cherdymova et al., 2018; Shirley and Gore, 2019). With all of these efforts to mitigate response bias, we assume that most interviewees were comfortable and confident in expressing their attitudes towards fishing cat. It might be wise for future research to incorporate a revised interview approach to obtain more reliable information, including audience segmentation to more appropriately define and target the hunting or retaliation group (*e.g.*, Jones et al., 2019).

We are also proposing that future studies, including our continued work in the region, extend the study area to include the west side of the railway, as some parts of fishing cat home range polygons overlapped with those areas (Fig. 4B). Long-term population monitoring is also recommended to assess population health over time, improve habitat management, and achieve long-term conservation planning goals. Additional surveys in adjacent, coastal wetland areas likely to contain suitable habitats for fishing cats, should also be conducted to fill the geographical knowledge gap for fishing cats in Thailand, and update their national status. Finally, a social science investigation of the motivation and/or awareness of people to either apply or not apply non-lethal conflict mitigation measures, as well as perceptions regarding their overall effectiveness, could ultimately improve their more widespread adoption or implementation, and inform any supportive outreach programs that address conflict-related threats.

Conservation Implications

Based on our findings, to help ensure the long-term viability of the fishing cat population in and around KSRY, we make several recommendations relating to safeguarding important existing habitats, the mitigation of human-fishing cat conflict, and the reduction or preventing of hunting and retaliatory killings. First, we recommend the creation of a special program that exempts landowners from government policies and penalties applicable to them if they *do not* convert fishing cat habitat to production land. Similarly, additional policies that incentivize landowners to preserve their land *for* fishing cats (*e.g.*, tax reductions) would be welcome benefit to the region. We also recommend that the railway construction effort underway consider adopting approaches to maximize connectivity of existing habitat, minimize population isolation, and reduce the potential for both inbreeding and genetic drift (Barrientos and de-Água, 2017; Jakes et al., 2018; Barrientos et al., 2019). This might include the installation of culverts and underpasses, the construction of raised trestle bridges, and consideration of alternative local options for the placement of infrastructure. Efforts related to patrols could also regularly include the community outside of the protected area, possibly through increased staffing or other support mechanisms. An outreach program targeting local communities could help maintain positive attitudes toward fishing cats as they have for other species (Espinosa and Jacobson, 2012), and also promote information on potential conflict mitigation techniques. Lastly, supplemental incomes to aid people suffering economic hardships due to fishing cats, or offset damage incurred, such as via compensation or community-based ecotourism, might also help discourage persecution (Mishra et al., 2003; Dickman et al., 2011; Bauer et al., 2015). Although some of our recommendations might be site-specific, others might have wider applicability to fishing cat conservation wherever they face similar or more diverse threats. We hope our interdisciplinary findings can contribute important baseline data upon which to better understand not only the basic ecology of fishing cats in this geographically isolated stronghold, but also highlight the role human attitudes and beliefs have on persecution, potential conflict mitigation interventions, and conservation planning, for threatened carnivores in human-dominated landscapes.

Acknowledgements

We appreciate financial supports from the King Mongkut's University of Technology Thonburi, the ASAHI Glass Foundation, and Society for the Preservation of Endangered Carnivores and their International Ecological Study (S.P.E.C.I.E.S.). We would like to thank the Thai Department of National Parks, Wildlife and Plant Conservation, KSRY director R. Asawakultharin and all park staff for supporting our work. We thank M. Grainger for the useful comments and M. Namkhan for helping on GIS analysis. We especially thank our field assistants (J. Tananantayot, R. Angkaew, S. Khamngam, N. Sangpan and E. Sidum) for field work, and appreciate local villagers who participated in questionnaire survey.

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Table 1. Description of study area variables for spatially explicit capture–recapture modeling to estimate fishing cat density.

Variables	Name	Description and measurement details
1. Human disturbance		
• Distance to the railway	railway	Distance from railway (km) calculated using GIS database in each camera-trap station.
• Distance to highway	road	Distance from main highway (km) calculated using GIS database in each camera-trap station.
• Threat level	threat	Threat level extracted from threat level map. The level ranges from 0 to 3: 0 = no hunting and persecution in the area, 1 = hunting or persecution in the past but not presently, 2 = hunting and/or persecution occurred in the past and sometimes recently, and 3 = hunting and persecution continues unabated from the past to present
2. Trapping effort	trap-day	Sum of trap-days (24h-periods) in each camera-trap station.
3. Areas of each land use type		
• Traditional aquaculture	Aqu	Sum of the area (km^2) of traditional aquaculture pond
• Agriculture	Agr	Sum of the area (km^2) of agriculture land, paddy field and plantation
• Abandoned area	Aba	Sum of the area (km^2) of abandoned land, shrubland and unpaved roads
• Natural forest	Nat	Sum of the area (km^2) of mangrove forests and marsh (water level < 1 m)
• Unsuitable areas	Unu	Sum of the area (km^2) of human settlement,

		commercial-oriented aquaculture ponds, limestone mountain, marsh or wetland area (water level > 1 m), water bodies
4. Areas of land use change		
• Traditional aquaculture pond change	C.aqu	Sum of the area (km^2) of traditional aquaculture pond that were converted to unsuitable areas from 2016 and 2018
• Agriculture change	C.agr	Sum of the area (km^2) of agricultural land, paddy field and plantation that were converted to unsuitable areas from 2016 and 2018
• Abandoned area change	C.aba	Sum of the area (km^2) of abandoned land, shrubland and unpaved road that were converted to unsuitable areas from 2016 and 2018
• Suitable areas change	C.all	Sum of the area (km^2) of all suitable areas that were converted to unsuitable areas from 2016 and 2018

Table 2. Area (km^2) for five major land use types for our study area. Areas in 2009 and 2016 were calculated from land use maps provided by the Thailand Land Development Department database, while those from 2018 were calculated from our updated 2016 map using field survey data and high-resolution satellite images available in Google Earth

Land use type	Year 2009	Year 2016	Year 2018
Traditional aquaculture	72	69	58
Agriculture	100	117	87
Abandon area	48	82	90
Natural forest	68	18	44
Unsuitable areas	48	50	57

Table 3. Model selection for fishing cat density estimates based on spatially-explicit capture-recapture framework at Khao Sam Roi Yot National Park, Thailand, between November 2018 and April 2019. '*K*' is the number of parameters included in the model, 'AICc' is Akaike's Information Criteria corrected for small sample size, 'ΔAICc' is the absolute difference in AICc, and 'w_i' is a measure of relative support for each model.

Models	*K*	AIC_c	ΔAIC_c	w_i
g0~bk, σ~h2	6	1342.61	0.00	0.93
g0~bk, σ~1	5	1347.72	5.11	0.07
g0~1, σ~Agr + Aba	6	1387.61	45.00	0.00
g0~1, σ~h2	5	1387.70	45.09	0.00
g0~1, σ~C.aqu + C.agr	6	1395.70	53.10	0.00
g0~1, σ~Agr + Nat	6	1397.27	54.66	0.00
g0~1, σ~Agr	5	1397.68	55.07	0.00
g0~1, σ~Aqu + Agr	6	1398.66	56.06	0.00
g0~1, σ~Aba + Nat	6	1399.20	56.59	0.00
g0~1, σ~Aba	5	1401.14	58.54	0.00
g0~1, σ~C.aqu	5	1402.21	59.61	0.00
g0~1, σ~Aqu + Aba	6	1404.11	61.50	0.00
g0~1, σ~C.aqu + C.aba	6	1404.89	62.29	0.00
g0~Bk, σ~1	5	1405.03	62.42	0.00
g0~1, σ~C.agr	5	1407.11	64.50	0.00
g0~threat, σ~1	5	1408.83	66.23	0.00
g0~threat + railway, σ~1	6	1409.43	66.82	0.00
g0~1, σ~C.agr + C.aba	6	1409.71	67.10	0.00
g0~1, σ~C.all	5	1410.81	68.20	0.00
g0~b, σ~1	5	1412.27	69.67	0.00
g0~1, σ~1	4	1413.91	71.30	0.00
g0~1, σ~Aqu	5	1415.66	73.05	0.00
g0~1, σ~ threat	5	1415.91	73.31	0.00
g0~1, σ~Nat	5	1416.10	73.49	0.00
g0~ trap day, σ~1	5	1416.38	73.77	0.00
g0~1, σ~C.aba	5	1416.57	73.96	0.00
g0~road, σ~1	5	1416.64	74.03	0.00
g0~railway, σ~1	5	1416.66	74.05	0.00
g0~1, σ~Aqu + Nat	6	1418.09	75.48	0.00
g0~1, σ~Unu	6	1419.58	76.97	0.00

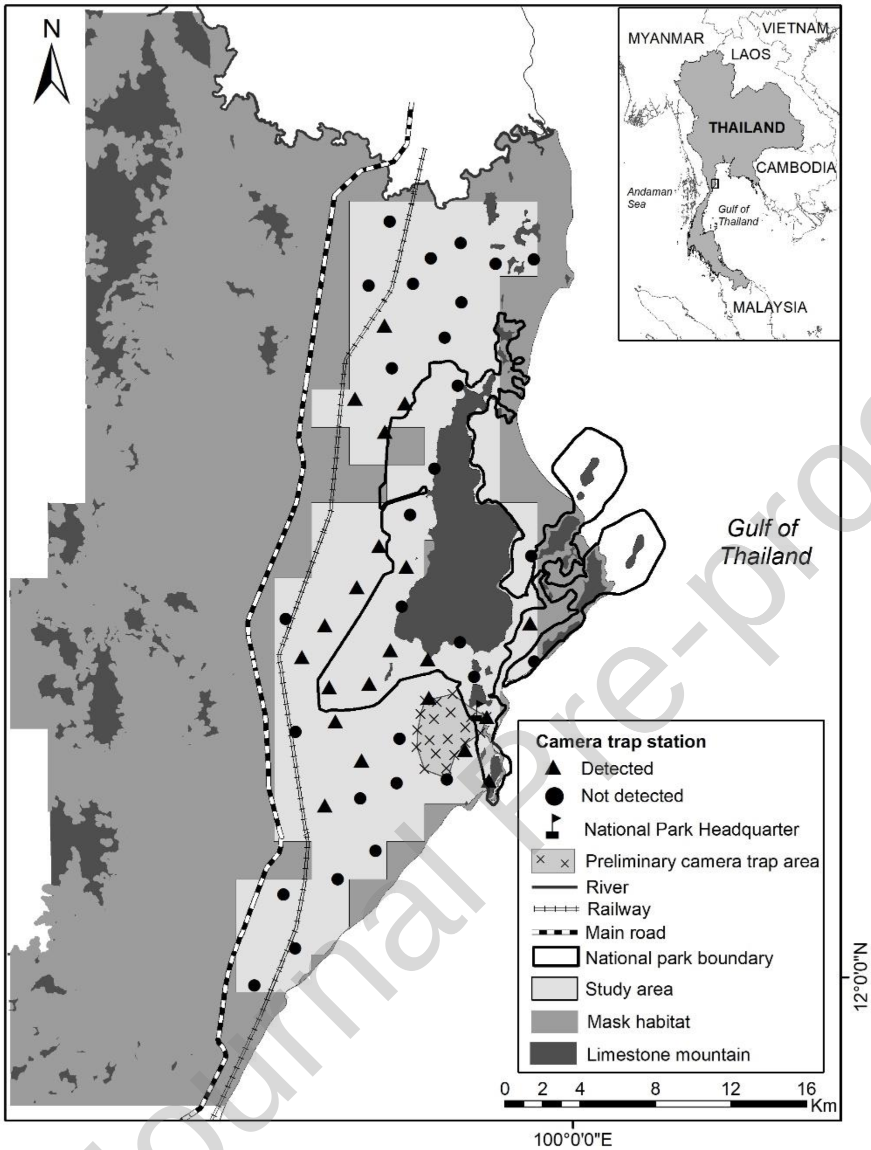

Fig. 1. Map of the study area at Khao Sam Roi Yot National Park, Thailand (light grey) depicting camera-trap stations with detection (triangles) and non-detection (circle) of fishing cats during our survey conducted between November 2018 and April 2019. The preliminary camera-trap survey area is indicated by an area with 'X' cross-hatching near the national park headquarters; the protected area boundary is indicated by the solid line. Masked habitat is shown in the medium grey, and limestone mountains/peaks are represented by a dark grey color.

Fig. 2. Commercial-oriented aquaculture ponds (left) and traditional aquaculture ponds (right). Commercial-oriented ponds are deeper with more machinery and pond’s beds are covered by plastic sheets, while traditional ponds had more vegetation cover and lack of these infrastructure.

Fig. 3. Four left-flank photographs of three fishing cats. Two top photos are the same fishing cat individual captured at different camera-trap station and occasion. Two bottom photos are two different fishing cat individuals captured at the same camera-trap station with the top left photo.

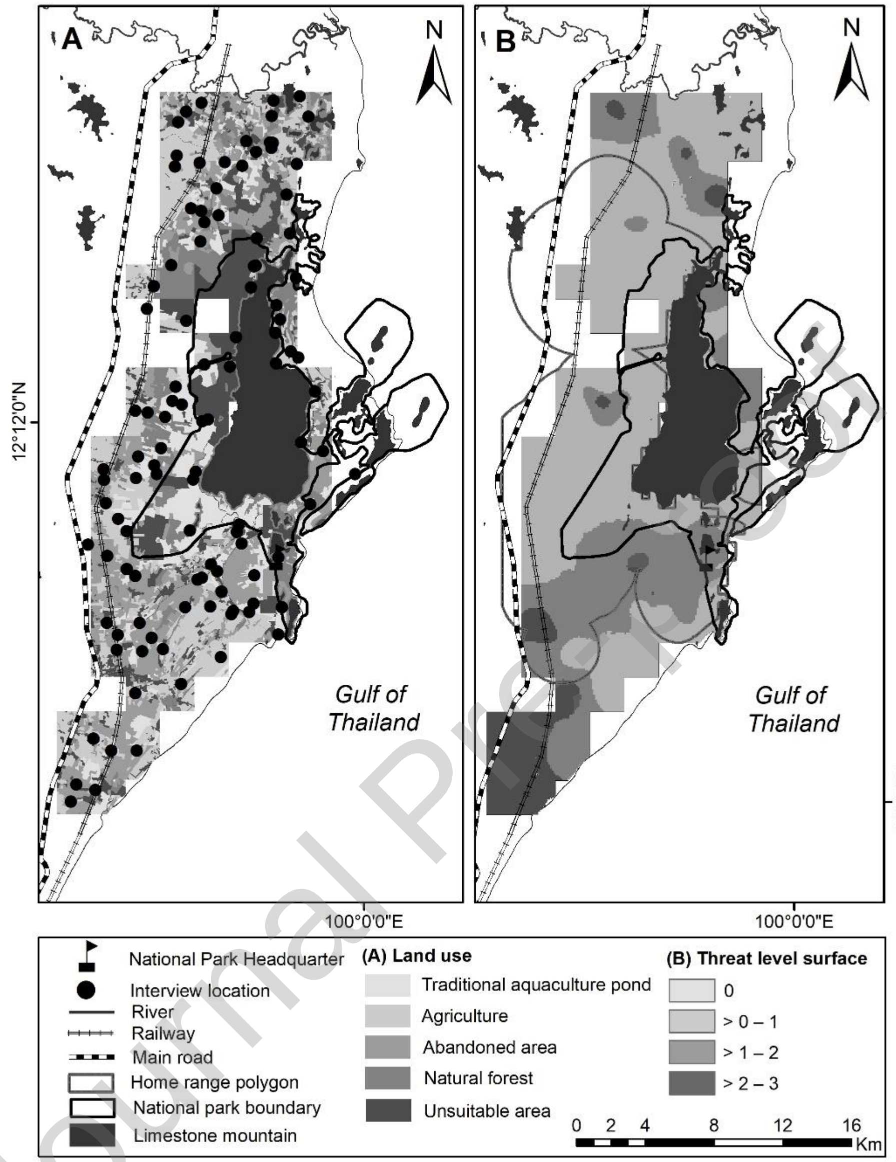

Fig. 4. (A) Location of 113 interviewees (circle) and land use types around Khao Sam Roi Yot National Park; (B) The threat level in 4 categories: 0 = no hunting and persecution in the area, > 0–1 = hunting or persecution in the past 5 years but not currently occurring, > 1–2 = hunting and/or persecution in the past 5 years and some recent occurrences, and > 2–3 = continued hunting and persecution over the past 5 years unabated through the present.

Fig. 5. Fencing adjacent to the double-track railway project intended to prevent livestock collisions (west side of the study area).

Declaration of interests

☒ 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.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: