Research Article

Using relative abundance indices from camera-trapping to test wildlife conservation hypotheses – an example from Khao Yai National Park, Thailand

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Abstract
Khao Yai National Park (KYNP) is well known for its biodiversity and has the potential to serve as a regional model for wildlife conservation. From October 2003 through October 2007, the managers of KYNP conducted a Carnivore Conservation Project to develop and implement long-term monitoring of their large mammal populations. We present these data as an example to demonstrate the usefulness of long-term camera-trapping despite data that cannot be fitted to mark/recapture or occupancy statistical frameworks. Overall, a relatively high number of camera trap photographs was obtained for viverrids (four species; 44 photos) and ursids (two species; 39 photos). However, a relatively low number (range, one to eight) of camera trap photographs was obtained for each of the four felid species and two canid species detected by cameras. Of a total survey effort of 6,260 trap nights, no tigers (*Panthera tigris*) were detected by camera traps, suggestive of at best a small, non-viable tiger population. Compared to previous camera-trapping efforts at KYNP, we expanded intensive sampling beyond the core area to include all zones and edges of the park. We found significantly lower relative abundance indices (RAIs) for certain mammal species, and collectively for all mammals compared to data obtained in 1999-2000 from 34 similar survey locations, suggesting population declines linked to increased human activity. Information from long-term camera-trapping can provide critical information on the occurrence of elusive species, hotspots, the role of invasive or domestic species, and an indication of the effectiveness of patrolling and other management and conservation interventions.

Keywords large mammals, protected area management, wildlife monitoring

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Introduction

Camera-trapping has long been used to survey for and monitor the occurrence of wildlife species around the world [e.g., 1-5]. Much attention has been focused on using camera-trapping to detect otherwise elusive species, including charismatic examples such as tigers (*Panthera tigris*) [e.g. 1], snow leopards (*Panthera uncia*) [e.g., 2], and giant pandas (*Ailuropoda melanoleuca*) [3]. Initially, much of this camera-trapping was relatively untargeted and data collection was not standardized. Over time, these efforts have been replaced by more systematic sampling approaches, often centered on identifying individual animals in a mark-recapture framework [e.g., 1-2], or using patch-occupancy approaches to assess detection probabilities for species presence/absence [e.g., 4]. However, photos collected by less statistically sound sampling designs may still provide large amounts of useful data. The sheer volume and importance of this data is exemplified by a new internet site hosted by the Smithsonian Institution, where camera-trappers from around the world, including a wide range of contributors from scientists to the general public, can post their photos and data (http://siwild.si.edu). Using the example of Khao Yai National Park (KYNP) in Thailand, we illustrate the value and usefulness of camera trap photos from generic monitoring surveys. Camera traps can indicate relative abundance of a species with the assumption that photo detection rates are related to animal abundance [5]. We used monitoring data obtained by ranger-based surveys to 1) assess relative abundance indices (RAIs) for important wildlife species, 2) calculate what camera-trapping effort may be necessary to detect most large-mammal species to assess a sampling/monitoring strategy, and 3) identify how these data can be used to delineate carnivore hotspots for special management and protection inside protected areas.

KYNP is Thailand's first national park, established in 1962, and covers 2,168 km^2. It has been the focus of a few long-term wildlife monitoring programs [6-7], and has the potential to represent a regional model for wildlife management because of its status as one of the largest national parks in Thailand's system of protected areas, its importance to the Thai people [8], and its status as part of the Dong Phayayen-Khao Yai Forest Complex (DPKYC), a UNESCO World Heritage site [9]. The DPKYC includes five protected areas totaling 6,155 km^2 of natural habitat supporting significant biodiversity components for Thailand, potentially including 391 bird and 60 mammal species [10]. Of the mammal species found within the complex, 46 species have been documented within KYNP. There have been detailed studies in KYNP providing valuable information on carnivore species, including tiger, leopard cat (*Prionailurus bengalensis*), and clouded leopard (*Neofelis nebulosa*) [11-15]. However, many of KYNP's mammalian species are understudied and information about them was obtained secondhand, often as part of tiger surveys.

We present KYNP as an example to demonstrate how basic and continued wildlife monitoring using standard camera-trapping can be used as an integral tool for park management and anti-poaching efforts in protected areas of the region. We use the data to assess the spatial distribution of wildlife and identify potential conservation hotspots for carnivores. Such monitoring will prove extremely useful for site-level efforts to combat poaching and illegal wildlife trade. It can also provide baseline data for subsequent targeted studies using more specialized sampling and study designs such as mark/recapture and patch occupancy.

Methods

Study area

Surveys were conducted in KYNP (14°26'29''N; 101°22'11''E) at the western edge of the DPKYC, Thailand. Elevation at KYNP ranges from 100 m to 1,350 m. The climate is monsoonal, with distinctive wet (Jun.-Sep.), cool (Oct.-Jan.), and dry (Feb.-May) seasons. Annual rainfall is 2,270 mm; mean annual temperature is 27°C. More than 80 percent of the park is forested. Vegetation types include tropical rainforest, dry evergreen forest, hill evergreen forest, mixed deciduous forest, dry dipterocarp forest, and grassland [16]. Mixed deciduous forest is the dominant type with hill and dry evergreen forest occupying higher elevations.

Zone-based monitoring and seasonal data collection

A monitoring team of KYNP park rangers conducted the field surveys. The rangers were selected following a 12-day training course for rangers from DPKYC. During the course, participants were challenged with topics covering the scope of the field research process, from planning field surveys, to systematic data collection and reporting of data, and adapting future survey plans based on findings. The course covered wildlife monitoring techniques including line transect surveys and camera traps to increase the capacity of park rangers for biodiversity monitoring.

Camera trap surveys were conducted from October 2003 through March 2007 with sampling conducted in each of KYNP's 22 management zones (Fig. 1). Management zones are of unequal size and approximately follow watershed boundaries. Teams surveyed two zones per month. We randomly selected survey zones each month, but ensured that all zones were monitored at least once during the study. We randomly chose four zones (KY04, KY15, KY18 and KY20) for repeated data collection across each season. We could only repeat four zones in each season because of time and staff constraints. The repeated data collection of four management zones did not involve replicated camera sample locations; rather, new randomly selected grid-squares were chosen.

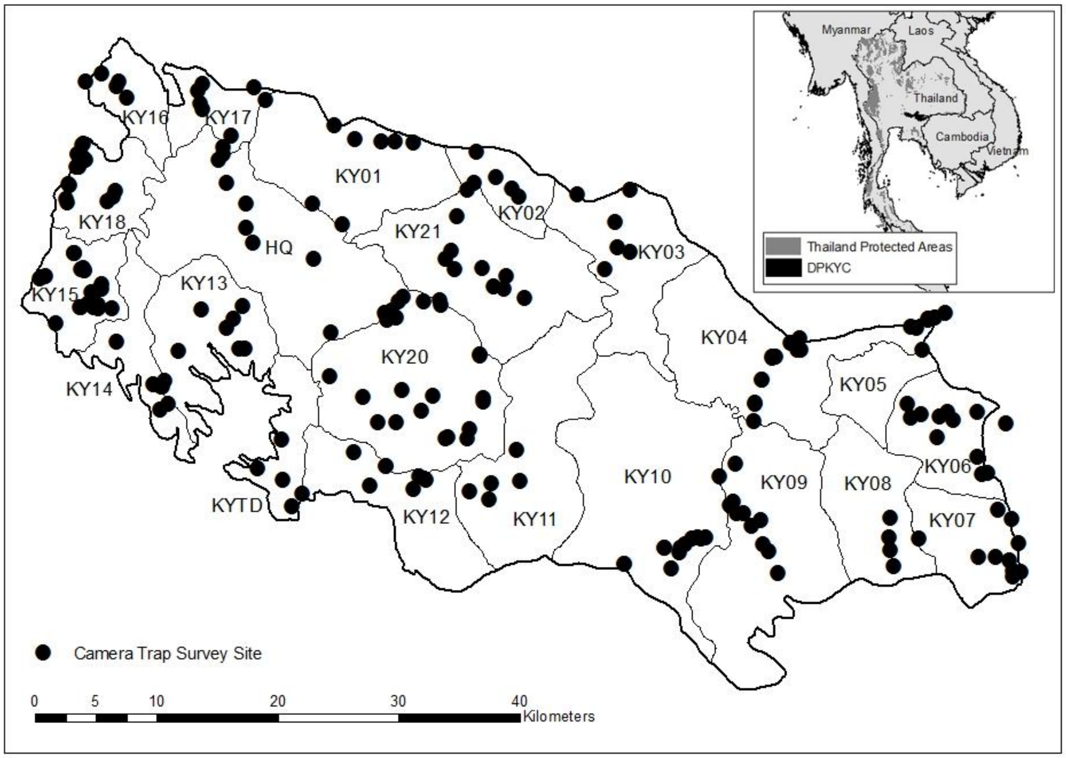

Fig 1. Khao Yai National Park (KYNP) is divided into 22 management zones that were used for monitoring. Locations of camera traps (n=217) are indicated by black dots. Inset: KYNP is at the western side of the Dong Phayayen-Khao Yai Forest Complex (DPKYC) in central Thailand.

Camera-trapping

To detect and record wildlife, we employed 15 camera traps (CamTrakker® CamTrak South, Inc., Watkinsville, GA 30677 USA) with an infrared sensor to detect animal movement. Camera traps did have visible flash which may have been detected by wildlife or people. During each month, four to eight camera traps were placed in each of the two survey zones dependent on the number of working cameras. We divided survey zones into 1-km^2 blocks and randomly chose blocks for camera locations. Within the block, teams set up camera traps along wildlife trails and stream beds. Thirty-four sampling locations were chosen because they had been used by a previous monitoring program [13] and therefore we were interested in comparing our results with that study. We aimed to leave camera traps in the forest for three weeks since previous experience with this model [13] indicated this was the expected life of the batteries. Due to work schedule conflicts, cameras were often picked up earlier or later, but were only retrieved after a minimum of 21 days. We conducted camera surveys at 217 locations (Fig. 1), resulting in 6,260 trap nights. Camera traps at an additional 44 locations did not yield data because they malfunctioned or were stolen, lost, or damaged by weather, elephants (*Elephas maximus*), or poachers.

All camera traps were operational 24 hours per day, recorded time and date for each exposure, and had a 20-second delay between photographs. We placed camera traps on a tree ~50 cm from the ground and 1-2 m from the monitoring area. We aimed the sensor parallel to the ground to monitor a conical area approximately 1 m in diameter at 10 m distance. We report number of animal detections and an RAI for each species. To compute the RAI for each species, all detections for each species are summed for all camera traps over all days, multiplied by 100, and divided by the total number of camera trap nights. We calculated RAI for each species as the number of photo captures per 100 trap nights to facilitate comparisons with previous studies at the same site [13] and other parts of the region. Animal detections were considered independent if the time between consecutive photographs of the same species was more than 0.5 hours apart, a convention which follows O'Brien et. al. [17]. Rather than identifying individuals, our focus was on comparing photo rates between areas and seasons, so the arbitrary time between independent photos should not introduce bias toward either one of these factors. Furthermore, this time of independence was used for data collection during a previous survey [13]. Photos with more than one individual in the frame were counted as one detection for the species.

To evaluate the effect of season on wildlife RAIs, we used a Kruskal-Wallis test. For analyzing differences in mammal RAIs between the edge of the park (< 5 km from boundary) and the park's interior (≥ 5 km from boundary), we performed a two-sample t-test. Five kilometers was chosen for a buffer because it falls between the maximum distance from the edge and mean distance from the edge that domestic dogs were detected and serves as a proxy for the penetration of human-disturbance from the forest edge. To quantify the optimal number of camera trap locations (i.e., how many locations needed to be sampled to capture most of the diversity of KYNP), we plotted mammal species detected against sample locations and fitted a hyperbola curve. We repeated this analysis to obtain species accumulation curves for carnivores only and other mammal species, respectively. To understand the time required to detect mammals if they are present at a sampling location, we plotted the frequency distribution of nights to first detection for carnivore or non-carnivore species and used curve fitting to determine the peak. All curve fitting was done using SigmaPlot 10.0 (Systat Software, Point Richmond, CA).

To offer a baseline to interpret our camera-trapping results, we compared our RAIs for all photographed species to data from camera-trapping surveys done at KYNP during 1999-2000 [13]. It is difficult to compare RAIs between projects because of differences in detection probabilities at different locations; therefore, we only included sample locations that we could pair directly with locations from the previous survey (located < 2.5 km apart; n = 34 pairs). We performed a Wilcoxon signed-rank test to test the null hypothesis that there is no difference in a species' RAI between our current surveys and the surveys conducted four to six years previously.

Camera traps also recorded human traffic (rangers, visitors, poachers, villagers) and domestic dogs. Poachers were identified if they were carrying a gun, a carcass, or animal parts, a bag to transport plant material/tree bark, or were accompanied by a dog.

Spatial modeling

To assess the spatial distribution of all wildlife qualitatively, we selected *a-priori* environmental factors to investigate their effect on wildlife spatial distribution. The environmental factors included distance (m) to nearest human or domestic dog photo detection (*Intruder*), distance (m) to nearest ranger (*Staff*), distance (m) to nearest poacher, villager, or domestic dog (*NonStaff*), distance (m) to park boundary (*Edge*), and elevation (m; *Elev*). We used ArcGIS 9.2 Spatial Analyst, a Geographic Information System

(GIS) software program developed by ESRI, to calculate all distances using the Euclidian distance function. Elevation was taken from a digital elevation map supplied by the park.

We then used multiple logistic regression to explore the associations between the detection/non-detection data for wildlife as the dependent variable and the five environmental factors as the independent variables. We used an information-theoretic approach and Akaike's Information Criterion (AIC) to choose the model with the highest likelihood value and to weight (through model averaging) the relative likelihoods (importance) of the different predictor variables. We divided the data set into a 75 percent training subset and a 25 percent testing subset, which resulted in 144 wildlife detections from 215 survey locations (two survey locations were dropped due to incorrect GPS locations that were not located within the park).

We created a predictive occurrence map in ArcGIS using map algebra in the Spatial Analyst raster calculator. To delineate areas with better than by chance prediction of wildlife, we used *a-priori* prevalence values (144 wildlife detection locations out of 215 total locations) as the "presence" threshold (0.67 detection). We calculated the classification accuracy of the model using the testing subset in a contingency table.

Results

Species accumulation, sampling effort, and trap nights

Camera traps recorded 650 photographs, of which 19.8% (n = 129) were of carnivores, 42.8% (n = 278) were of non-carnivore mammals, 22.9% (n = 149) were of birds, 8.2% (n = 53) were of humans, and 2.6% (n = 17) were of domestic dogs. We could not determine species in 3.7% (n = 24) of the photographs due to poor focus, lighting, or angle. Species captured on film included 26 mammals (14 carnivore species; 12 non-carnivore mammal species; Appendix 1).

RAIs did not differ among seasons (Kruskall-Wallis: 1.704, p = 0.427). Inspection of species accumulation curves showed that the number of locations varied to capture 75 percent of non-carnivore mammals (23 locations), all mammals (53 locations), and carnivore species (75 locations) at KYNP (Fig. 2a). Time (nights) to first detection showed a skewed distribution for detecting non-carnivores (max: 1.5 days) and carnivore species (max: 2.7 days; Fig. 2b). After 14 days, 80 percent of all camera traps had captured at least one mammal species (Fig. 2b). For individual species, days to first detection ranged from three (binturong [*Arctictis binturong*]) to 23 (palm civet [*Paradoxurus hermaphroditus*]; Fig. 3).

Carnivores

Based on camera-trapping, we found 14 carnivore species in the park, including four viverrids, four felids, two canids, two ursids, one mustelid, and one herpestid (Appendix 1). Of these species, 10 were documented 10 times or less, and one species (dhole [*Cuon alpinus*]) is globally threatened (Endangered) [18; Appendix 1]. The number of photos per carnivore species ranged from one for marbled cat (*Pardofelis marmorata*; RAI = 0.02; Appendix 1) to 37 for large Indian civet (*Viverra zibetha*; RAI = 0.59; Appendix 1). Asiatic black bear (*Ursus thibetanus*; n = 21) was the second-most common carnivore species photographed (Appendix 1). Camera traps did not detect tigers. The coat pattern of the clouded leopards that we observed in KYNP is similar to those of mainland Southeast Asian clouded leopards and different from the clouded leopard (*Neofelis diardi*) on Borneo and Sumatra [19; Fig. 4].

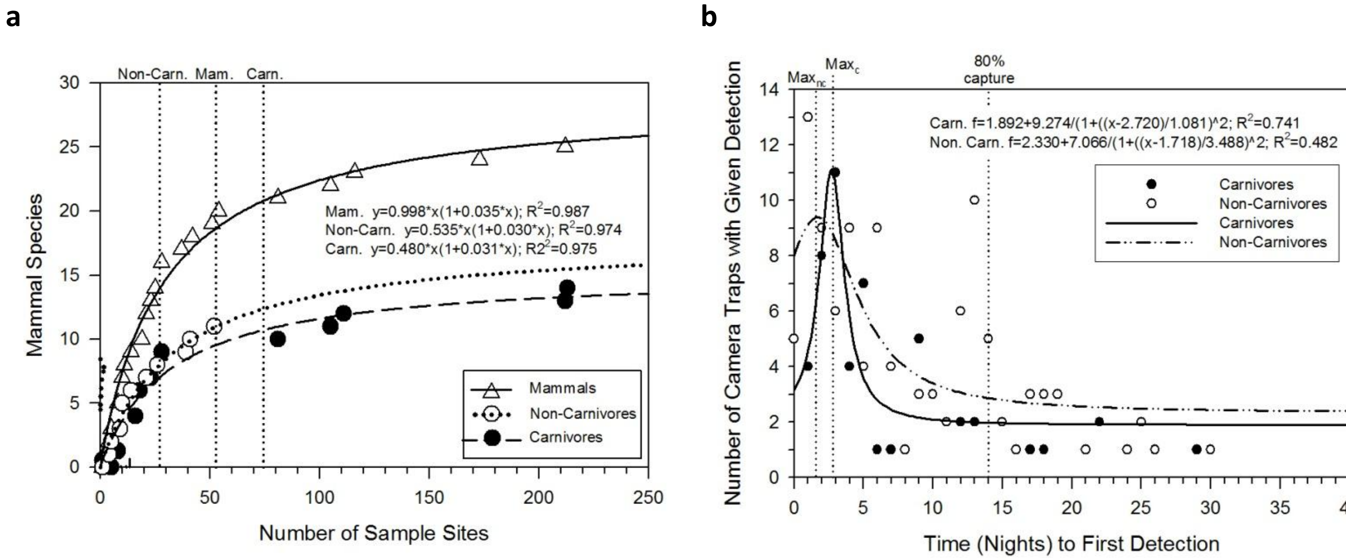

Fig. 2. Camera-trapping indices for species detection. Species accumulation curves to demonstrate the number of sampling sites needed for 75 percent detection for all mammals, non-carnivore mammals, and carnivore species (a). Time to first detection for camera traps for detecting non-carnivore and carnivore species (b).

Non-carnivorous mammals

Barking deer (*Muntiacus muntjak*; 60 photos) and Eurasian wild pig (*Sus scrofa*; 60 photos) were the two most common herbivore species detected during camera trap surveys (Appendix 1).

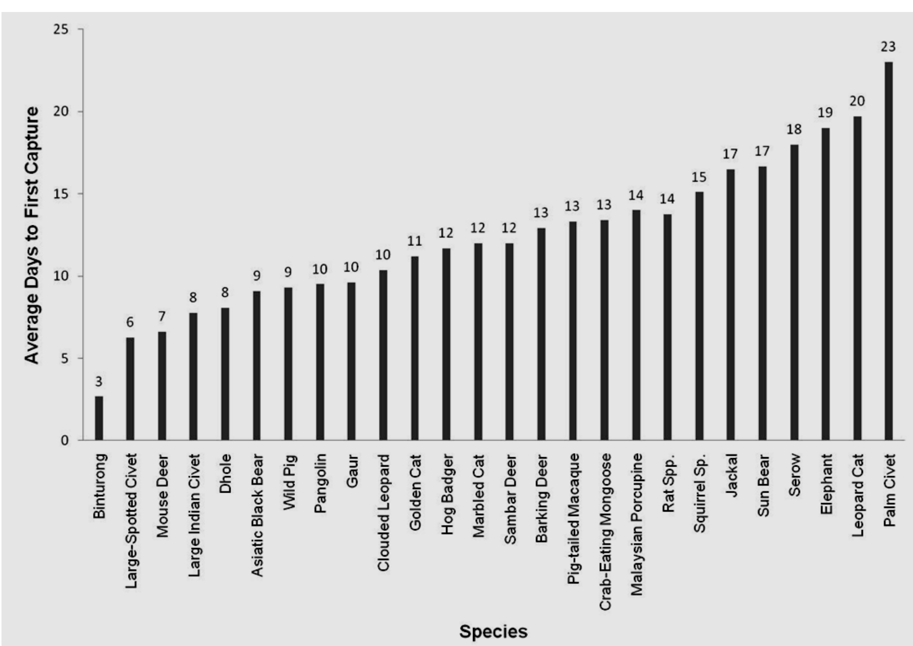

Fig. 3. Average day to first photographic detection for species in Thailand's Khao Yai National Park.

Human traffic

In addition to documenting the presence and distribution of wildlife, camera traps also recorded human traffic (poachers, rangers, villagers, tourists) and domestic dogs inside the park (n = 70; Appendix 1). The majority of poacher photographs were taken on the eastern boundary of the park (Appendix 2a); however, domestic dogs (most likely accompanied by people) intruded well into the interior of the park (mean distance from edge = 2.72 km; maximum distance from edge = 6.59 km; Appendix 2b).

Table 1. Multiple regression models used in predicting wildlife presence using five environmental variables. Models are ordered from the highest to the lowest AIC, with the top three models shown. Relative variable importance is also listed.

Model	AIC	Relative variable importance
*Intruder + Staff + NonStaff + Edge + Elev**	196.3	
Intruder + Elev	190.7	
NonStaff + Elev	190.6	
Elev**	**189.1**	
Elev		0.89
Edge		0.28
NonStaff		0.23
Intruder		0.22
Staff		0.22

Distance (m) to nearest intruder (*Intruder*), distance (m) to nearest staff (*Staff*), distance (m) to nearest non-staff (*NonStaff*), distance (m) to park boundary (*Edge*), and elevation (m; *Elev*); *AIC = Akaike Information Criterion;* *Global Model; **Model chosen for modeling wildlife prediction; Relative variable importance calculated from averaged model parameters of all possible models.

Wildlife distribution

We found a significant difference in wildlife RAIs between interior zones of the park and zones near the boundary (< 5km from the park boundary; $t(94.434)= 2.755$, $p=0.007$). More interior zones of the park supported a larger average RAI (0.141) than surrounding areas (0.078). Jackals (*Canis aureus*) were only detected at one location and were less widely distributed than dholes (Appendix 2b). While both bear species and prey for mid- to large carnivores were distributed throughout the park, felids were found central and to the northwest corner of the park (Appendix 2c, d, e). In KY20, we photographed three felid species (leopard cat, Asiatic golden cat [*Pardofelis temminckii*], and marbled cat) at the same location within 12 days of each other. Additionally, KY09 yielded a location with at least four species of carnivores (large Indian civet, binturong, mongoose species [*Herpestes* spp.], and Asiatic black bear).

Table 2. Parameters of model chosen to predict wildlife presence at Khao Yai National Park (n=150 training set observations).

	Coefficient	Std. Error	z value	P value
Intercept	0.0959865	0.3000046	0.320	0.7690
Elev	0.0013612	0.0005908	2.304	0.0212 *

Significance code: 0.01 '*' Elev = elevation (m)

Our global model (before parameter selection) contained five co-variables. The best model fit included *Elev* (Table 1). Wildlife detections increased as elevation increased. We then produced a predictive occurrence map (Appendix 2f) from the logistic function of the chosen model (Table 2) and calculated the ability of the model to correctly predict wildlife presence for our sub-set of testing data. Overall, the model correctly predicted wildlife presence/absence at 60 percent of the 65 test locations used in the analysis. The total area of predicted wildlife presence is 1,344 km^2 which amounts to 62 percent of the total park area.

Comparison with previous KYNP data

Since differences in RAIs may be a result of a number of factors including differences in detection probabilities between surveys, we report only the strongest differences in RAI as indication of true differences in species abundance. In comparison with past surveys by Lynam et al. [13] conducted in 1999-2000, we detected a significant difference in clouded leopard (Z=-1.992, p=0.046), barking deer (Z=-2.939, p=0 .003), all combined mammals (Z=-2.671, p=0.008), and overall intruders (any humans and domestic dogs; Z=-3.438, p=0.001; Appendix 3).

Discussion

Species numbers

Our project built on previous wildlife monitoring in KYNP [13] by including formerly under-surveyed management zones close to the boundary of the park. Camera-trapping is one monitoring tool available to park authorities for evaluating the occurrence of some medium-large mammals, and to estimate relative abundance patterns across management zones for species that are highly detectable by camera traps. Fourteen out of the 19 carnivore species previously confirmed for KYNP [10] were also detected by our camera traps. We did not photograph small Indian civet (*Viverricula malaccensis*), masked palm civet (*Paguma larvata*), yellow-throated marten (*Martes flavigula*), ferret-badger (*Melogale* sp.), or tiger. A previous monitoring program [13] also did not detect these species (apart from tiger). Yellow-throated marten, masked palm civet, and ferret badgers are primarily arboreal, and so camera traps may not be effective in detecting these species. The small Indian civet was detected in one photo in May 2007 in the Headquarters Zone during a short camera-trapping survey outside of our main survey efforts. While we did not obtain photographic evidence of tigers, the last footprint evidence of tiger occurrence in KYNP is a record documented with a plaster cast and photograph taken by our team in the Headquarters Zone in October 2005 (47P 0754639 1599044; Fig. 5). That tigers were not recorded by camera-trapping adds evidence to the notion that the species has disappeared from the park other than perhaps transient individuals. Additionally, we supplemented park records with detections of previously unrecorded rare and elusive species: the large-spotted civet (*Viverra megaspila*) and golden jackal.

Wildlife distribution patterns

Distribution patterns detected in our study indicate that wildlife relative abundance in KYNP is significantly higher in central parts of the park than in marginal areas near park boundaries. This concurs with the findings of a previous study, which found that track encounter rates and camera trap rates for mammals decline with increasing distance from the park headquarters towards the park edge [13]. A similar pattern was documented for bears, elephants, and ungulate species in KYNP through universal kriging [20].

Most carnivore species were not widely dispersed across sampling locations, but clustered in a few locations. Notably, we detected three felid species (leopard cat, golden cat, and marbled cat) with the same camera in zone KY20, adjacent to the park Headquarters Zone. The survey location was along a ridge-line which may have been a natural travel route for the felids. Additionally, the high elevation of the area may be less accessed by people, reducing human impacts. The three observations are in agreement with previous findings that small cat sympatry is the norm in Southeast Asian forests [e.g., 21-23]. These observations are of management interest because the presence of three wild felids may indicate sufficient prey resources for all species, and/ or natural protection from humans that benefits all species along the ridge of this management zone.

Detecting poachers and domestic dogs

Camera traps provided direct evidence of poaching including photos of individuals carrying turtles, birds, and other forest products, and/or carrying rifles at night using headlamps. Furthermore, nine camera traps were stolen or destroyed by poachers apparently concerned that they will be identified by authorities. These events were concentrated along the eastern border of the park furthest from the park headquarters, indicating human pressures are greatest in management zones KY04, KY05, KY06, KY07, KY08 and KY09 (Appendix 2a). While a significant portion of the poaching in Khao Yai is still carried out by people who live in villages adjacent to the protected area, some of the poaching for aloewood (*Aquilaria crassana*) and wildlife is carried out by Cambodian nationals who leave trash with identifiable Khmer script. These workers illegally enter Thailand, move into the park from the east, and extract wildlife products to sell in Cambodian and Thai markets [24].

Camera traps recorded domestic dogs roaming as far as 7 km from the park boundary. These are most likely hunting dogs entering the park alongside their owners, since domestic/feral dogs from surrounding villages would only forage short distances into the park on their own. However, wherever they are, dogs undoubtedly increase hunting pressure on prey species and also must be considered competitors of native scavengers [25]. In addition, they occasionally may kill other carnivore species such as civets and dholes [26-27]. Finally, domestic dogs are well known carriers for diseases such as rabies, canine distemper virus (CDV), and canine parvovirus that have led to epidemics in a variety of wild carnivore species, such as African wild dogs (*Lycaon pictus*), lions (*Panthera leo*), and Ethiopian wolves (*Canis simensis*) [28-31]. The potential consequences of disease spill-over that domestic dogs might have on the wildlife of KYNP are far-reaching. For example, CDV is reported to not only affect canids, felids, and hyaenids, but also mustelids (e.g., otters), procyonids (raccoons), ursids (bears), and viverrids [e.g., civets; 32]. Based on our documented dog-ranging behavior into KYNP, and home range sizes for feral dogs reported to be up to 10.5 km^2 [33], there is high potential for contact (direct or indirect) between domestic dogs and carnivores in KYNP that could lead to transmission of fatal infectious diseases.

Changes in relative abundance

Overall mammal abundance is different in KYNP and perhaps has declined in the four to six years since the Khao Yai Conservation Project was initiated by the Wildlife Conservation Society. While cause and effect have not been measured, our data showed significantly lower RAIs for clouded leopard, barking deer, humans, and mammals in KYNP. To evaluate our reported RAIs, it is helpful to consider that in Thailand's largest National Park, Kaeng Krachan National Park, where Asiatic leopards (*Panthera pardus fusea*) are the dominant large carnivore, leopards were detected 3.71 times per 100 camera trap nights [34], double the RAI of the most abundant carnivore at KYNP (large Indian civet, Appendix 3). This suggests that the relative abundances of mammalian predators and their prey in Khao Yai are suppressed, and this may be related to increased human activity. Supporting the possibility of impact from human activity is the relative variable importance calculated from the averaged model parameters of all possible models. Elevation was the most important variable impacting wildlife presence and wildlife detections increased as elevation increased. This may be because higher elevations of the Park are less accessible to poachers.

In turn, the suppressed wildlife abundances in KYNP may be related to decreased or less effective patrol activity in the second phase of the Khao Yai Conservation Project compared to the first few years (2000 – 2003). Both clouded leopards and barking deer are common targets for poachers and subsistence hunters at Khao Yai (K. Jenks, unpublished interview data). Furthermore, even though total human RAI values were significantly lower in comparison with past surveys, we may have underestimated the amount of human traffic as it is highly likely that people became increasingly aware of the cameras and actively avoided them.

Estimating abundance

RAIs are not synonymous with an actual index of relative abundance because they have not been correlated with data on population size of each species. However, it is still useful to explore patterns in our camera trap data since relatively little camera trap data has been published from this region. Much camera trap data that has been collected across Asia has been the result of opportunistic sampling. While this data does not qualify for statistical trend analysis in the same way as occupancy modeling, the presentation of the data itself is useful as it can be used to inform decision makers. For example, recorded presence of a rare species is valuable by itself. The evidence from KYNP is compelling and indicates that wildlife populations continue to decline in this protected area.

Mark/recapture and patch occupancy provide extremely useful tools for the detection of trends in wildlife population abundance and species presence/absence. The main advantages they offer are explicit treatment of detection probabilities, error assessments, and estimation of confidence intervals [35]. However, not all data can be collected in this way for a wide range of reasons, from lack of technical capacity to logistics, or simply that fact that we are dealing with legacy data that was collected before the application of the technique had found its way into general practice. Yet, data from these studies is still valuable and should be used to address research and conservation questions.

Our data represents one of the legacy projects, where the principal investigators at the time were not familiar with a patch occupancy framework for data collection and analysis. *Post-hoc* fitting of our sampling scheme into an occupancy analysis was not possible because of the small number of independent sample locations (fewer than six) in each zone during a sampling period and because of the violation of closure over such a long sampling period. However, we demonstrated how this presence data can be used in spatial modeling and regression analysis to study the spatial distribution of wildlife and human intruders. We also showed how it can be used to identify potential conservation hotspots for selected taxonomic groups, such as carnivores.

Fig. 4. Zoomed camera trap photograph of a clouded leopard.

Fig. 5. Footprint evidence of tiger in the Headquarters Zone of Khao Yai National Park, October 2005. Photo Credit: T. Redford/FREELAND

Implications for conservation

Other protected areas and carnivore communities

Our monthly placement of camera traps provided a comparison across all seasons and also yielded useful information for future monitoring programs. Because of the lack of significant difference in RAIs among seasons, we recommend that future studies concentrate surveys during the dry season. This would greatly reduce the weather-related camera malfunctions in the tropical environment, while not losing data on species detections.

We recommend that 75 randomly placed sample locations within a grid system throughout a large study area are enough to detect mammal species over an area of approximately 2,000 km^2 of similar forest type. Our data demonstrate that most of the mammal species at KYNP could likely be documented by sampling fewer than 75 locations, and based on our species accumulation curve, adding additional sampling locations would not have substantially changed our inferences about diversity patterns at KYNP. We caution, however, that the spatial distribution of our samples may be a strong factor in this conclusion.

Our data regarding average time to first photo capture for individual species (Fig. 3) may be helpful for researchers planning future camera trap studies of specific species in a similar habitat.

Management and research recommendations

Camera-trapping at KYNP should be carried out every year in the dry season in blocks of two-week surveys. Unlike many protected areas in Southeast Asia that have very restricted budgets and resources available for management, KYNP has hundreds of staff, and one of the largest annual budgets of all Thai protected areas available to commit to park management, especially with respect to tourism activities. However, despite the importance of wildlife for sustainable tourism, protecting and monitoring wildlife has historically been assigned a low priority at KYNP. We advocate the adoption of a system of regular monitoring using a range of methods by dedicated teams of rangers, separate from important anti-poaching patrol efforts. Our data indicate that on average, 80 percent of detections of mammals using camera traps were within 14 days. A two-week time period is therefore adequate for documenting the presence of mammals. We also recommend that in order to fully document diversity of mammals at KYNP, camera-trapping will need to be augmented by other methods such as spotlight surveys to detect small carnivores such as primarily arboreal civets, and rare species such as ferret badgers [36]. Live trapping methods should be most useful for assessing the small mammal prey base of carnivores since this group is under-sampled with camera trap methodology [37].

We suggest that zones KY09 and KY20 be recognized by managers as potential carnivore diversity hotspots warranting increased protection from illegal human activity. More intensive camera-trapping should be done in these areas to determine the reasons for the higher number of species detected there, and whether or not the pattern holds over the long term. Focusing additional anti-poaching resources in these zones would be a relatively easy-to-implement management step that should positively impact overall carnivore diversity at KYNP if done effectively. Our photos provide strong evidence that harmful or disruptive activities inside the park (such as active poaching, aloewood collection, and the simple presence of humans and dogs) are a continuing threat for KYNP and its wildlife. Increased patrolling along the park's eastern border, a potential major entry point for poachers, is also likely to be a deterrent to poaching.

Additionally, recovering tigers at KYNP will require a long-term commitment to protecting the vulnerable zones in the park. However, with the loss of tigers, the dhole has assumed the role as the functionally top predator in KYNP. Dholes are an endangered species that has historically not received appropriate conservation attention by KYNP park managers but needs the same level of protection afforded by flagship species such as tigers, gibbons (*Hylobates spp.*), and hornbills (*Buceros spp.*).

Conclusion

Despite continued threats and a decrease or near extirpation of tigers, KYNP supports a diversity of carnivore species of conservation concern, including clouded leopards, dholes, and small felids. Dedicated efforts to monitor wildlife using simple tools such as camera traps will be essential to KYNP's future mission as part of a World Heritage Area. An added benefit of these monitoring activities is the fact that they increase the visitation of remote areas by park staff. Continued monitoring will provide critical information on the occurrence of native species, threats hotspots, the role of invasive or domestic species, and an indication of the effectiveness of patrolling and other management and conservation interventions.

Since the completion of our project, newly developed techniques have been developed combining camera-trapping data with occupancy analysis [38] using a new biodiversity indicator, the Wildlife Picture Index (http://www.wildlifepictureindex.org/examples/demo_home.htm) [38]. These techniques may prove useful in the future for answering more detailed questions about wildlife distribution and conservation status, and might be suitable endeavors for researchers or graduate student projects.

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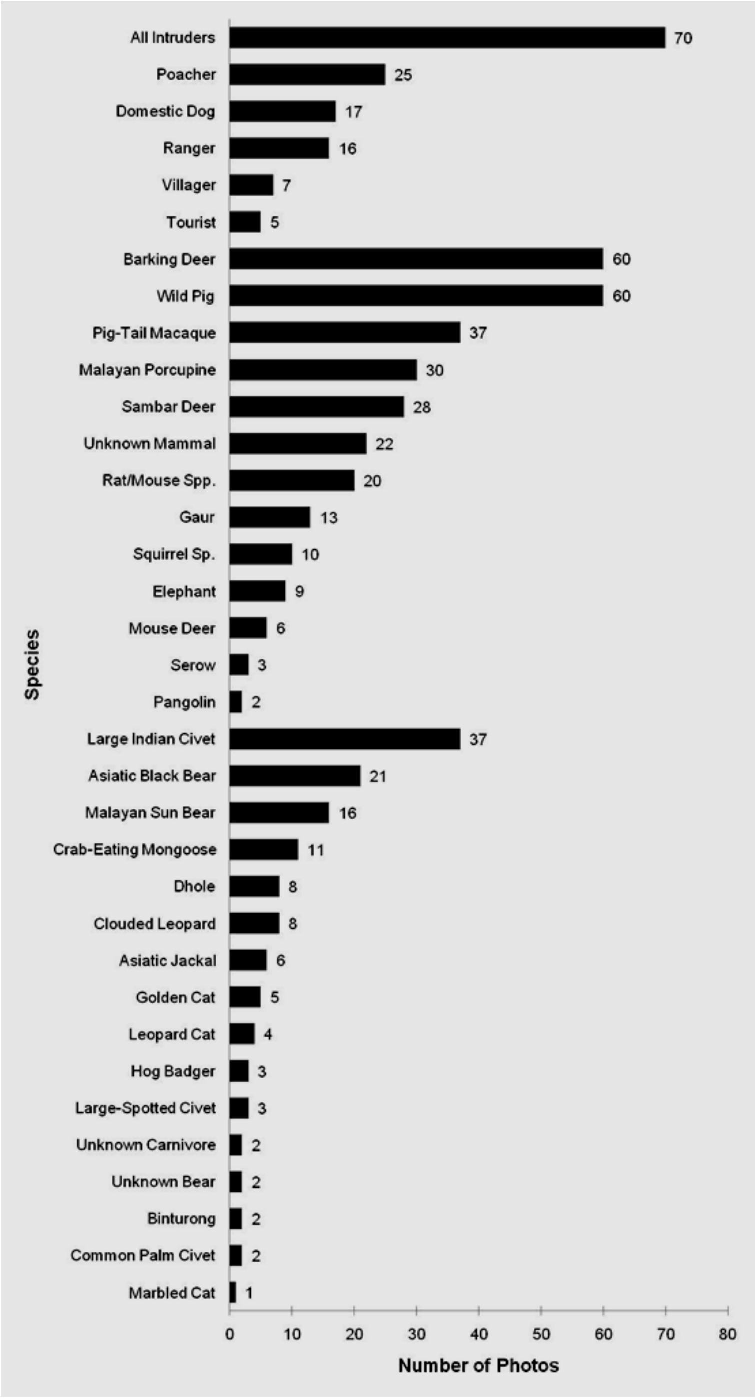
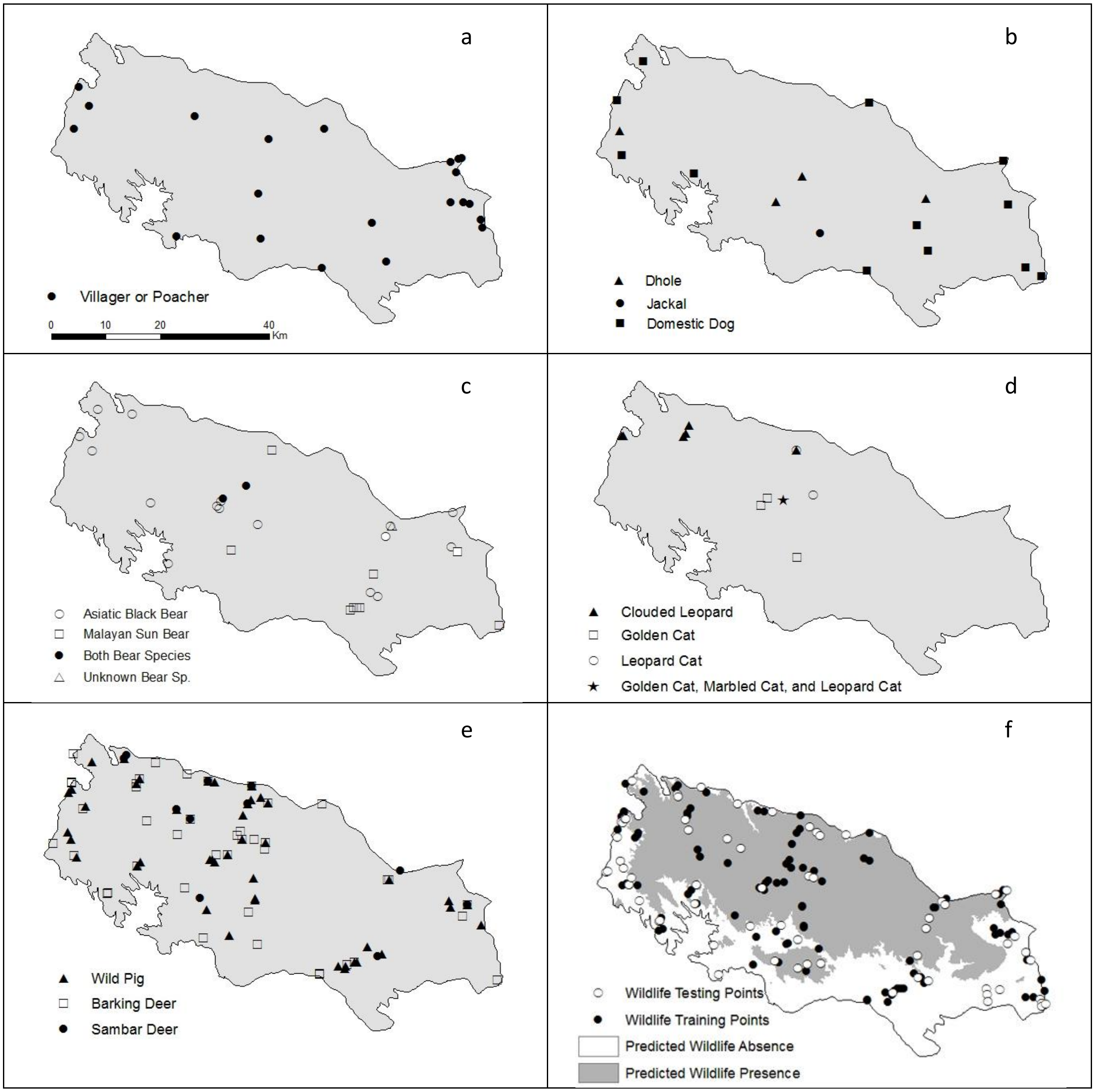
Appendix 1. Frequency of photo captures (October 2003 through March 2007) for wildlife and human traffic in Thailand's Khao Yai National Park.



Appendix 2. Distribution maps of (a) villages and poachers, (b) canids, (c) bears, (d) felids, (e) prey for mid-to large carnivores, and (f) model surface predicting wildlife presence. We counted a photographed person as a poacher if they were carrying a gun, a carcass or animal parts, a bag to transport plant material/tree bark, or were accompanied by a dog.



Appendix 3. Comparison of average wildlife relative abundance indices (photos/100 trap nights) at 34 camera trap survey locations between 1999-2003 and 2003-2007.

IUCN Status[1]	Species		Present survey[2]	Lynam et al. 2003[3]
EN	Tiger	*(Panthera tigris)*	0.00	0.14
V	Clouded Leopard	*(Neofelis nebulosa)*	**0.06**	**0.48 ***
NT	Asiatic Golden Cat	*(Pardofelis temminckii)*	0.00	0.07
LC	Leopard Cat	*(Prionailurus bengalensis)*	0.12	0.80
EN	Dhole	*(Cuon alpinus)*	0.02	0.45
LC	Golden Jackal	*(Canis aureus)*	0.12	0.00
NT	Large Indian Civet	*(Viverra zibetha)*	1.40	1.23
V	Large-spotted Civet	*(Viverra megaspila)*	0.10	0.00
LC	Common Palm Civet	*(Paradoxurus hermaphroditus)*	0.08	0.20
V	Binturong	*(Arctictis binturong)*	0.15	0.07
LC	Mongoose spp.	*(Herpestes spp.)*	0.37	0.27
LC	Yellow-throated Marten	*(Martes flavigula)*	0.00	0.54
NT	Hog Badger	*(Arctonyx collaris)*	0.10	0.71
V	Asiatic Black Bear	*(Ursus thibetanus)*	0.14	0.00
V	Malayan Sun Bear	*(Helarctos malayanus)*	0.27	0.73
LC	Eurasian Wild Pig	*(Sus scrofa)*	0.78	1.28
EN	Asian Elephant	*(Elephas maximus)*	0.42	0.25
V	Gaur	*(Bos gaurus)*	0.34	1.06
V	Sambar Deer	*(Rusa unicolor)*	1.85	2.43
LC	Barking Deer	*(Muntiacus muntjak)*	**1.11**	**5.47 ****
DD	Lesser Mouse-Deer	*(Tragulus javanicus)*	0.08	0.56
V	Mainland Serow	*(Capricornis milneedwardsii)*	0.06	0.00
LC	Malayan Porcupine	*(Hystrix brachyura)*	0.75	1.69
EN	Sunda Pangolin	*(Manis javanica)*	0.12	0.00
V	Pig-Tailed Macaque	*(Macaca nemestrina)*	0.58	2.50
LC	Total Human Traffic	*(Homo sapiens, Canis familiaris)*	**1.59**	**5.66 ***
	All Mammals		**9.68**	**21.97 ****

(1) IUCN status: LC=least concern; V=vulnerable; NT=near threatened; EN=endangered; DD=data deficient [18].

(2) These data represent a sub-set of data collected during the present survey (sub-set taken from October 2003-November 2006; n=1,017 trap nights). A total of 34 survey locations (within 2.5 km) was selected for comparison to data from Lynam et al. [13]. RAI's in bold represent a significant difference **p<0.01 and *p<0.05 in species' values in comparison to Lynam et al. [13].

(3) Data from Lynam et al. [13] collected from January 1999 through July 2000 (n=1,226 trap nights).