

Opportunity for Thailand's forgotten tigers: assessment of the Indochinese tiger *Panthera tigris corbetti* and its prey with camera-trap surveys

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Abstract Dramatic population declines threaten the Endangered Indochinese tiger *Panthera tigris corbetti* with extinction. Thailand now plays a critical role in its conservation, as there are few known breeding populations in other range countries. Thailand's Dong Phrayayen-Khao Yai Forest Complex is recognized as an important tiger recovery site, but it remains poorly studied. Here, we present results from the first camera-trap study focused on tigers and implemented across all protected areas in this landscape. Our goal was to assess tiger and prey populations across the five protected areas of this forest complex, reviewing discernible patterns in rates of detection. We conducted camera-trap surveys opportunistically during 2008–2017. We recorded 1,726 detections of tigers in 79,909 camera-trap nights. Among these were at least 16 adults and six cubs/juveniles from four breeding females. Detection rates of both tigers and potential prey species varied considerably between protected areas over the study period. Our findings suggest heterogeneity in tiger distribution across this relatively continuous landscape, potentially influenced by distribution of key prey species. This study indicates that the Dong Phrayayen-Khao Yai Forest Complex is one of the few remaining breeding locations of the Indochinese tiger. Despite limitations posed by our study design, our findings have catalysed increased research and conservation interest in this globally important population at a critical time for tiger conservation in South-east Asia.

Keywords *Bos gaurus*, distribution, Dong Phrayayen-Khao Yai Forest Complex, Indochinese tiger, *Panthera tigris corbetti*, prey abundance, *Rusa unicorn*, *Sus scrofa*

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Introduction

The tiger *Panthera tigris* has suffered catastrophic declines in its population (96%) and habitat (95%) over the past century (Nowell & Jackson, 1996; Goodrich et al., 2015; Wolf & Ripple, 2017). Evidence suggests only 42 source sites (i.e. sites with breeding populations that have the potential to support future recovery of the tiger over a larger area) remain across the species' range, totalling 90,000 km² (5.9% of current range; Walston et al., 2010). Habitat loss has been particularly acute in South and South-east Asia, with a 41% reduction from 1996 to 2006 (Sanderson et al., 2006) and an estimated forest loss of 71,134 km² in priority tiger conservation landscapes from 2001 to 2014 (Joshi et al., 2016).

The Indochinese tiger *Panthera tigris corbetti* is one of six extant tiger subspecies and is categorized as Endangered on the IUCN Red List (Lynam & Nowell, 2011; Goodrich et al., 2015). It was historically distributed throughout most of mainland South-east Asia (Luo et al., 2004, 2019) across Cambodia, Lao, Myanmar, southern China, Thailand and Viet Nam (Lynam, 2010). Evidence suggests three range countries (Cambodia, Lao and Viet Nam) have lost viable populations, and the Indochinese subspecies may qualify for Critically Endangered status (Lynam & Nowell, 2011). Despite previous evidence of a viable breeding population in Nam Et Phou Loey National Protected Area in Lao (Johnson et al., 2006; Vongkhamheng, 2011), recent evidence suggests tigers may have been extirpated from the country (Rasphone et al., 2019). Tigers are probably extinct in Cambodia, prompting plans for reintroduction (Gray et al., 2017), and in Viet Nam there have been no confirmed tiger records in > 20 years (Lynam & Nowell, 2011). A paucity of reliable population data in current range countries has obscured these declines (Lynam & Nowell, 2011), and information on remaining populations is needed urgently.

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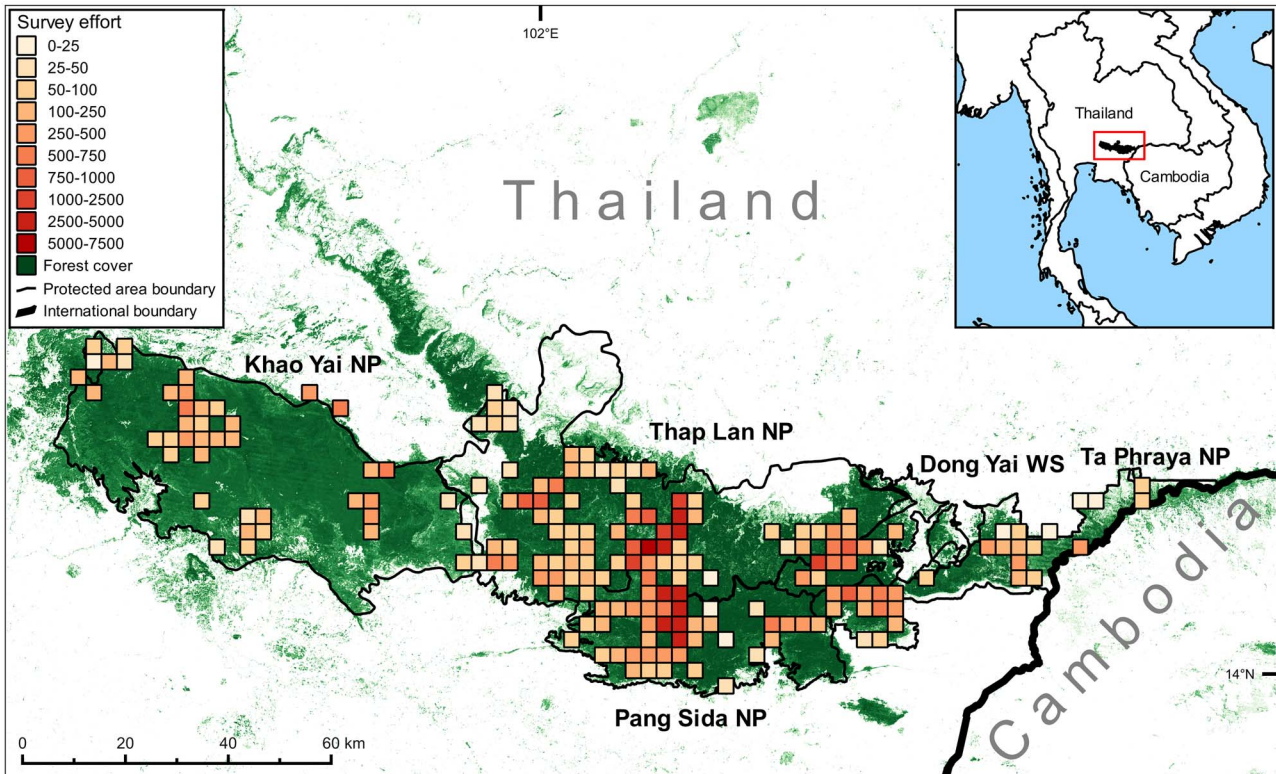


FIG. 1 Survey locations in the Dong Phrayayen-Khao Yai Forest Complex, which includes five protected areas: Dong Yai Wildlife Sanctuary, Khao Yai National Park, Pang Sida National Park, Thap Lan National Park and Ta Phraya National Park. Survey locations are depicted as 3 × 3 km grids and shaded according to total survey effort (number of camera-trap nights) from 2008–2017. Forest cover adapted from Hansen et al. (2013).

It is possible that the only remaining source sites for the Indochinese tiger are in Myanmar and Thailand. However, studies in key landscapes in Myanmar have documented low and potentially declining numbers (Lynam et al., 2009; Rao et al., 2010; Naing et al., 2019; Moo et al., 2018) reinforcing the importance of Thailand as the tiger’s last stronghold in the region. In Thailand’s 2010 action plan, the national tiger population was estimated to be 190–250 individuals (Pisdankam et al., 2010). A recent, updated government report included landscape-specific population estimates of at least 101–128 individuals (DNP, 2016), with potentially only two viable populations, in the Western Forest Complex (25,000 km²) and the Dong Phrayayen-Khao Yai Forest Complex (6,155 km²) in eastern Thailand.

Although a number of tiger-focused studies have been conducted in other parts of Thailand, including ongoing monitoring in the Western Forest Complex (Duangchantrasiri et al., 2016), data from the Dong Phrayayen-Khao Yai Forest Complex are limited. Information on tigers there has originated primarily from general assessments of faunal communities or other carnivores, or from interviews and personal communications (Lynam, 2001; Kanwatanakid et al., 2002; Lynam et al., 2006; Jenks et al., 2011). Evidence suggests that tigers may have been extirpated in Khao Yai National Park, but almost no information is available from other areas in

this forest complex. To our knowledge, there have been no studies focusing on tigers across this forest complex in its entirety. Comprehensive studies on prey species, an important factor for tiger distribution and persistence (Karanth & Stith, 1999; Karanth et al., 2004), are also lacking.

Given catastrophic population and range declines elsewhere in Thailand and South-east Asia, knowledge of the tiger population of the Dong Phrayayen-Khao Yai Forest Complex is of national, regional and global importance. Here, we describe results from the first camera-trap study focused on tigers and implemented across all protected areas in this landscape, conducted during 2008–2017. We aimed to assess tiger and prey populations and to identify any patterns in detection frequencies of tigers and prey species amongst protected areas. Our findings provide baseline information for tigers and their prey, and also document potentially important information on other mammal species of research and conservation interest.

Study area

The Dong Phrayayen-Khao Yai Forest Complex lies c. 160 km north-east of Bangkok (Fig. 1). To the east it partially borders the international boundary between Thailand and north-west Cambodia. The terrain is hilly, with altitudes

TABLE 1 Survey effort across protected areas in Thailand's Dong Phrayayen-Khao Yai Forest Complex during 2008–2017, showing camera-trap nights and total number of camera stations (stations with paired camera traps in brackets).

Year	No. of camera-trap nights / camera stations (paired stations)				
	Dong Yai WS ¹	Khao Yai NP ¹	Pang Sida NP ¹	Thap Lan NP ¹	Ta Phraya NP ¹
2008				535 / 22 (3)	
2009				2,886 / 89 (5)	
2010		126 / 3 (1)	339 / 26 (0)	4,965 / 151 (9)	
2011			6,727 / 149 (6)	2,172 / 36 (7)	
2012	1,574 / 57 (0)	2,402 / 38 (0)	5,092 / 94 (11)	1,804 / 16 (7)	
2013	1,564 / 38 (0)		3,802 / 56 (32)	2,260 / 14 (4)	844 / 30 (0)
2014		2,357 / 24 (0)	2,294 / 23 (1)	3,062 / 18 (4)	4,230 / 66 (2)
2015	210 / 6 (0)	2,539 / 26 (0)	4,242 / 22 (3)	3,636 / 15 (5)	690 / 6 (1)
2016	1,455 / 12 (0)	197 / 3 (0)	5,765 / 27 (10)	10,784 / 75 (71)	
2017 ²	68 / 4 (0)		437 / 15 (5)	851 / 28 (26)	
<i>Total camera-trap nights (%)</i>	4,871 (6.10)	7,621 (9.54)	28,698 (35.91)	32,955 (41.24)	5,764 (7.21)

¹WS, Wildlife Sanctuary; NP, National Park.

²January–February only.

of 100–1,351 m. The forest complex consists of five protected areas: Dong Yai Wildlife Sanctuary, Khao Yai National Park, Pang Sida National Park, Thap Lan National Park and Ta Phraya National Park (DNP, 2004). These parks are collectively inscribed on the UNESCO World Heritage List (UNESCO, 2017).

The complex contains all major forest types characteristic of eastern Thailand, but is primarily covered by mixed evergreen and mixed dipterocarp/deciduous primary and secondary forest. It also contains grassland/scrub areas, some of which are anthropogenic. These forests have been influenced to varying degrees by a complex history of human presence and exploitation, including logging, settlements, agriculture and other activities (Lynam et al., 2006). Currently, the complex is surrounded almost completely by a human-dominated matrix of villages, farmland and infrastructure.

Methods

We conducted camera-trap surveys during March 2008–February 2017. The study design was opportunistic because of limited resources, and data collection for the five protected areas varied in spatial and temporal extent (Supplementary Fig. 1, Supplementary Material 1), precluding analysis within an occupancy framework. We placed camera traps in locations suitable for tigers, to maximize detections. Such locations included geographical or topographic features (e.g. ridges, river valleys) and access roads or trails likely to be used regularly by tigers (Karanth, 1995; Karanth & Nichols, 1998). We also used tiger track and sign (e.g. pugmarks, scats), and presence of prey species, to identify prospective camera locations.

We considered consecutive detections of a species at one camera station to be independent if they occurred after > 30 minutes (O'Brien et al., 2003). Individual tigers were given

an alphanumeric identifier to compile detection histories. Tigers not conclusively identified were marked as unknown. We calculated detection rates of tigers and prey as number of detections per 100 camera-trap nights, with cumulative rates reported for each protected area across survey years. Although such indices do not reliably indicate abundance (Jennelle et al., 2002; Sollmann et al., 2013), we also carried out a comparative analysis of photographic capture rates for tigers and prey for all five protected areas (Supplementary Material 1).

Results

Camera traps were active for a total of 79,909 camera-trap nights at 914 locations. Survey effort varied significantly across protected areas. Thap Lan National Park (32,955 camera-trap nights) and Pang Sida National Park (28,698 camera-trap nights) accounted for c. 77.15% (61,653) of total camera-trap nights and c. 74.18% (n = 678) of stations. Survey effort by protected area and year is summarized in Table 1.

Surveys recorded 1,726 independent detections of tigers during the study period (Table 2). Tigers were documented in three of the five protected areas (Thap Lan National Park, Pang Sida National Park and Dong Yai Wildlife Sanctuary), with Thap Lan National Park and Pang Sida National Park accounting for > 99% of detections (1,203 and 516 detections, respectively). Tigers were detected in Dong Yai Wildlife Sanctuary only in 2016 (seven detections). Tigers were not detected in Khao Yai National Park and Ta Phraya National Park. Detection rates in Thap Lan National Park were higher than in Pang Sida National Park with cumulative means of 3.65 (range 0.54–7.18) and 1.80 (range 0.41–3.40) detections per 100 camera-trap nights, respectively.

TABLE 2 Cumulative tiger *Panthera tigris* detections and detection rates (detections per 100 camera-trap nights) for protected areas in the Dong Phrayayen-Khao Yai Forest Complex during 2008–2017.

Year	Dong Yai WS ¹	Khao Yai NP ¹	Pang Sida NP ¹	Thap Lan NP ¹	Ta Phraya NP ¹
2008				15 (2.80)	
2009				30 (1.04)	
2010		0 (0)	2 (0.59)	27 (0.54)	
2011			229 (3.40)	78 (3.59)	
2012	0 (0)	0 (0)	21 (0.41)	58 (3.22)	
2013	0 (0)		47 (1.24)	90 (3.98)	0 (0)
2014		0 (0)	38 (1.66)	220 (7.18)	0 (0)
2015	0 (0)	0 (0)	82 (1.93)	131 (3.60)	0 (0)
2016	7 (0.48)	0 (0)	92 (1.60)	493 (4.57)	
2017 ²	0 (0)		5 (1.14)	61 (7.17)	

¹WS, Wildlife Sanctuary; NP, National Park.

²January–February only.

In total, at least 16 adults were documented: seven females, seven males and 2–3 partially identified adults whose sex could not be confirmed (Table 3). A minimum of 12 individuals were documented in Thap Lan National Park, nine in Pang Sida National Park and two in Dong Yai Wildlife Sanctuary, with six being detected across multiple protected areas. The number of individual tigers detected was highly correlated with survey effort. Five individuals were recorded over a period of ≥ 8 years, and six individuals over 3–5 years (Supplementary Fig. 2, Supplementary Material 1).

Surveys documented successful breeding in 2015 and 2016, with six cubs/juveniles from four adult females. One litter of two juveniles were photographed without their mother (who could thus not be identified). One cub (C1), first documented in 2015, appeared to be independent from its mother by 2017.

We documented six potential prey species: gaur *Bos gaurus*, banteng *Bos javanicus*, Chinese serow *Capricornis milneedwardsii*, northern red muntjac *Muntiacus vaginalis*, sambar *Rusa unicolor* and wild boar *Sus scrofa*. We considered these species potential tiger prey based on information from Thailand and elsewhere within the tiger's range (Karanth et al., 2004; Sunquist, 2010; Steinmetz et al., 2013). All but one potential prey species (banteng) were documented in all five protected areas.

Mean cumulative detection rates of sambar (Supplementary Table 1, Supplementary Material 1) were considerably higher in Thap Lan National Park (14.70 detections per 100 camera-trap nights) than in other protected areas (0.02–8.67), whereas detection rates of other prey species were comparatively lower in this Park. Mean cumulative detection rates for wild boar were highest in Dong Yai Wildlife Sanctuary (6.67 detections per 100 camera-trap nights) and Pang Sida National Park (6.66). Sambar and

wild boar were generally detected more frequently than other prey species.

Although tigers were the primary focus of surveys, we also documented a number of other species (Supplementary Table 1, Supplementary Material 1), with 947 detections of other felids, including the Asiatic golden cat *Catopuma temminckii* (35 detections), mainland clouded leopard *Neofelis nebulosa* (158), marbled cat *Pardofelis marmorata* (30) and leopard cat *Prionailurus bengalensis* (724). We did not detect leopards *Panthera pardus*. We documented 37 mammal species in total, including one Critically Endangered, five Endangered, 10 Vulnerable, three Near Threatened and 18 categorized as Least Concern.

Discussion

This study provides insights into tigers and their prey in the understudied Dong Phrayayen-Khao Yai Forest Complex. Most of our detections of tigers were in Thap Lan and Pang Sida National Parks, potentially a result of larger survey effort (32,955 and 28,698 camera-trap nights, respectively, of a total of 79,909). This was the result of our opportunistic study design, which prioritized survey areas based on potential or confirmed tiger presence. Nonetheless, the absence of detections of tigers or their sign from two of the five protected areas, despite reasonable survey effort, suggests higher tiger abundance in these two Parks than elsewhere in this forest complex. Tiger presence across the complex appears to be heterogeneous, but to an unknown degree. Our records from Dong Yai Wildlife Sanctuary are from an area just outside the formerly known extant range of *P. tigris* (Goodrich et al., 2015). The lack of tiger detections from Khao Yai National Park is consistent with speculation that tigers have been extirpated from this protected area (Lynam et al., 2006; Jenks et al., 2011), although our survey effort and coverage in this Park was relatively low (7,621 camera-trap nights).

Although the number of tigers we documented in the complex is not a population estimate, our results suggest the population may be larger than previously assumed (Lynam, 2010), and also document the long-term persistence of a number of individuals in this area (Supplementary Fig. 2, Supplementary Material 1). To our knowledge, the photographs of tiger cubs we obtained are the first confirmed records of successful breeding in the forest complex since at least 1999 (Lynam et al., 2003, 2006; Jenks et al., 2011) and confirm that the site supports a breeding population. Breeding and subsequent dispersal could potentially result in expansion into Khao Yai National Park, and contribute to overall population recovery.

The presence of prey is important for tiger distribution, density and persistence (Karanth & Stith, 1999; Karanth et al., 2004), as noted by studies elsewhere in Thailand

TABLE 3 Individual tiger detections during the study period. Cubs are placed under their mother with the exception of C5 and C6 whose mother was not confirmed. Blank cells indicate no detections.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017 ²
Adult ID ¹										
Cub ID ¹										
M1	2									
M2	8	14	11	110	36	81	98	84	181	14
M3				2	3	1				
M4							26	24	61	11
M5	3	5	6	122	2	18	41	4	2	
M6									17	
M7						1			9	
F1	1	8	6	2		1			1	
F2						4	7	35	29	3
								3	13	
F3		1	1	44	33	18	49	51	154	16
									36	9
									33	5
F4		1	1	2	1				7	
F6						1		3	9	5
									1	1
F7						2	33	2	19	
F8									1	
(Mother unknown)										
									5	
									3	
UL1					1					
UR1					1					
UR2								1		
U	1	1	4	25	2	10	4	6	11	2
Detections	15	30	29	307	79	137	258	213	592	66
Stations	19	89	173	169	196	138	128	76	116	48
Camera-trap nights	535	2,886	5,430	8,899	10,872	8,470	11,943	11,317	18,201	1,356
Detection rate	2.80	1.04	0.53	3.45	0.73	1.62	2.16	1.88	3.25	4.87

¹M indicates male and F female individuals; U is used for individuals for which only one side was photographed, with L and R denoting whether the left or right flank of the individual was captured (sex could not be determined for these individuals and it is unknown whether UL1 is the same tiger as UR1 or UR2); U without L or R denotes detections of unidentified individuals (poor image quality or partial photographs).

²January–February only.

(Steinmetz et al., 2013; Simcharoen et al., 2014). Thap Lan and Pang Sida National Parks both had relatively higher rates of detection of sambar and wild boar, respectively, two species with which tigers have strong associations (Ngoprasert et al., 2012) and that are important prey elsewhere in the tiger's range (Sunquist et al., 1999; Biswas & Sankar, 2002; Hayward et al., 2012). However, a dedicated prey study is required to determine the extent to which tigers in these parks rely on these species. Low prey detection rates in Ta Phraya National Park and Dong Yai Wildlife Sanctuary could explain the absence of tiger detections in these two areas.

We did not detect leopards, which, given that they have similar behavioural patterns to tigers and can tolerate some degree of spatial overlap (Karanth & Sunquist, 1995; Andheria et al., 2007), suggests they may be absent from the forest complex. The Indochinese leopard *Panthera pardus delacourii* has not been detected recently in other parts of

South-east Asia, suggesting a decline in its population and range (Rostro-García et al., 2016). Abundance and diversity of suitable prey are important for the co-existence of tigers and leopards (Karanth & Sunquist, 1995; Andheria et al., 2007). Historical overhunting of prey in the forest complex could have driven competitive exclusion of leopards by tigers or other carnivores (Harihar et al., 2011; Volmer et al., 2017). Direct hunting by humans may have also driven population declines. However, given the paucity of reliable historical data, the reasons for the absence of the leopard in the Dong Phayeyen-Khao Yai Forest Complex remain unconfirmed.

Our data could not be used to estimate tiger occupancy or population size because the study design would violate key assumptions of the appropriate methods (Harmsen et al., 2010; Welsh et al., 2013). Methodologically rigorous study designs should be employed wherever possible in monitoring wildlife populations, but if resources are

constrained an opportunistic study design may be appropriate (Harihar et al., 2007; Stein et al., 2008; Johnson et al., 2016). Although conclusions that can be drawn from such studies are limited, they can contribute important insights into species presence in poorly studied areas (Stein et al., 2008; Jenks et al., 2011).

At the start of this study, tigers were believed to have disappeared from Khao Yai National Park (Lynam, 2001; Lynam et al., 2006; Jenks et al., 2011), information was lacking for other areas and resources were limited. In these circumstances, an opportunistic study design was suitable to address our fundamental research question, specifically, to confirm tiger presence. Early findings suggested tigers were present in the area, which enabled us to secure further funding and improved access to resources such as camera traps that were later used for tiger density and population estimates. Additional funding also enabled investments in law enforcement, patrol-based monitoring and community outreach programmes. To build on this work, we recommend additional analyses to model relationships between tigers, prey, threats and habitat required for spatial prioritization of protection and recovery interventions.

Our study provides insight into what is probably one of the most important extant tiger populations remaining in mainland South-east Asia. A comprehensive investigation of the tiger in other understudied sites in the region is urgently needed to generate a more accurate picture of their status. To recover and double the population of wild tigers (Global Tiger Initiative, 2011; Harihar et al., 2018), additional resources will need to be allocated to implement robust monitoring in sites where tigers remain.

To our knowledge, our work is the first to assess the tiger population across the Dong Phrayayen-Khao Yai Forest Complex and suggests this region is important for the Indochinese tiger, which has lost most of its range in South-east Asia. Our findings establish this forest complex as home to one of the few remaining breeding populations of Indochinese tigers, demonstrate the long-term persistence of some individuals, and suggest heterogeneous tiger presence across the five protected areas, potentially influenced by distribution of prey species. Our initial results have catalysed increased research and conservation investment in this landscape at a critical time for tiger conservation in South-east Asia.

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Conflicts of interest None.

Ethical standards This study abided by the *Oryx* guidelines on ethical standards. All research was conducted non-invasively.

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