CONSERVATION STATUS AND DISTRIBUTION OF THE INDOCHINESE TIGER *(PANTHERA TIGRIS CORBETTI)* AND OTHER LARGE MAMMALS IN A FOREST COMPLEX IN NORTHEASTERN THAILAND

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ABSTRACT

Thailand's forests are now largely fragmented with few large intact areas remaining to support wide-ranging fauna such as tigers and other large mammals. Phu Khieo Wildlife Sanctuary, in Chaiyaphum Province, is at the center of one of the potentially imponant areas for the survival of large mammals in Thailand and mainland Southeast Asia.. Intensive surveys using infrared-based camera-traps from May to July, 1998, revealed the presence of a single tiger and 16 other species of large mammals in a 4O-km2 area of the sanctuary near management facilities. Extensive sign searches and camera-trapping conducted over a 3OD-km2 area during 1997 and 1998 confmned the presence of the same individual tiger plus an additional 6 species of large mammals. The tiger had a minimum home range size pf 78 km2. Despite intact forest cover, a diverse and abundant assemblage of potential prey, and a survey effort involving 1.886 trap-nights of sampling, the tiger population at Phu Khieo appears decimated and possibly non-viable in the long term. Tiger numbers are probably significantly lower than habitat models would predict. This situation may be the combined result of past hunting pressure and present day competition for prey with subsistence poachers and other carnivores. Phu Khieo Wildlife Sanctuary is a high priority area for mammal conservation in Thailand but management intervention is urgently required to avert the loss of tigers.

Key words: camera-trapping, forest fragmentation, large mammals, Phu Khieo Wildlife Sanctuary. tigers

INTRODUCTION

Like other wide-ranging carnivorous mammals, the current geographic range of the tiger *(Panthera tigris)* is a fraction of what it was at the beginning of the last century (TILSON & SEAL. 1987). Remnant habitats for tigers in mainland Southeast Asia have become fragmented (COLLINS *Ef AL.*, 1991), and are now mostly isolated in a matrix of agricultural lands (ARBHABHIRAMA *ET AL.*, 1988). Thailand's remnant forests amount to 153,780 km2, or 30.0% of the total land area (PRAYURASIDDHI *ET AL.*, 1999). These forests comprise 19 disjunct forest complexes that now require forest management and conservation efforts. Fifteen of these areas potentially support Indochinese tigers *(Panthera tigris corbetti)*

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and other large mammals (SMITH *ET AL.*, 1999). However, despite extensive survey efforts for birds (ROUND, 1988), and documentation of remaining populations of wild cattle (SRIKOSAMATARA & SUTEETHORN, 1995), the status of wild populations of tigers and other large mammals in Thailand's forest complexes is poorly understood (RABINOWITZ, 1999).

One of the areas that holds promise for tigers and other large mammals in Thailand is the Phu Khieo-Nam Nao Forest Complex (PRAYURASIDDHI *ET AL.*, 1999) also known as the Western Isan Forest Complex (WIFC) (WIKRAMANAYAKE *ET AL.*, 1998). The purpose of this study was to determine the conservation status of tigers and other large non-volant mammals in this forest complex. We were interested in understanding two characteristics of tiger distributions: (1) what is the status of tigers in the best protected parts of the Phu Khieo -Nam Nao complex, and (2) what is the fine-scale distribution of tigers with respect to the distributions of other large mammals that are potential prey species. Intensive and extensive surveys using infrared-based camera-traps and track and sign searches revealed tfie distributions of tigers and other large mammals. It was of special interest to develop a survey protocol that could be readily adopted by government staff and applied for future monitoring of tiger populations and other large mammals.

STUDY AREA

Phu Khieo Wildlife Sanctuary, established on 26 May 1972, lies at the center of the Western Isan Forest Complex (Figure.I). All field work was carried out at Phu Khieo. The sanctuary covers an area of 1,560 km2 in Chaiyaphum Province, northeastern Thailand, approximately 550 km from Bangkok. The sanctuary comprises a steep-sided plateau ranging from 540 m at its base to 1,310 m at the highest peak. The central plateau lies at approximately 700-800 m elevation. The mean annual rainfall is 1,368 mm and mean temperature ranges from 18°C to 27°C. The plateau is drained by five watersheds: Lam Saphung, Lam Nam Chi, Huai Nam Phrom, Lam Dok, and Huai Sang. Locations in this study are reported in Universal Transmercator Units (UTM) Zone 47Q as eastings and northings, e.g. 776000 1824000. The headquarters are located near the centre of the sanctuary at Thung Kamang, a semi-natural grassland (775500 1813400).

Mixed deciduous forest is the dominant type in the lowlands with smaller areas of semi-evergreen forest (ROUND, 1988) and plantation. Hill and dry evergreen forest and semi-natural clearings dominate the higher altitudes. A number of grasslands exist in areas formerly cultivated by settlers, e.g. Thung Kamung. These settlers were relocated from the center of the sanctuary in 1972. Small stands of pine are found above 700 m. Thickets of bamboo associated with fire disturbance are scattered throughout. Fires are deliberately lit by poachers to attract deer and other browsing animals. Salt licks and mud holes occur across the plateau.

Phu Khieo lies adjacent to four other protected areas to the north (Nam Nao National Park, Pha Phung Wildlife Sanctuary) and west (Taboa-Huai Yai Wildlife Sanctuary, Tadmok National Park) providing a natural buffer to the sanctuary. Together these five protected areas form a contiguous forest block 3,840 km2 in size. Agricultural areas and human settlements lie directly adjacent to the sanctuary boundary in the south and east. Fifteen remnant forest areas lie disjunct to the Phu Khieo block of which 10 are protected areas. The Phu Khieo block and these 10 protected areas comprise the WIFC, which has a total area of 7,092 km2.

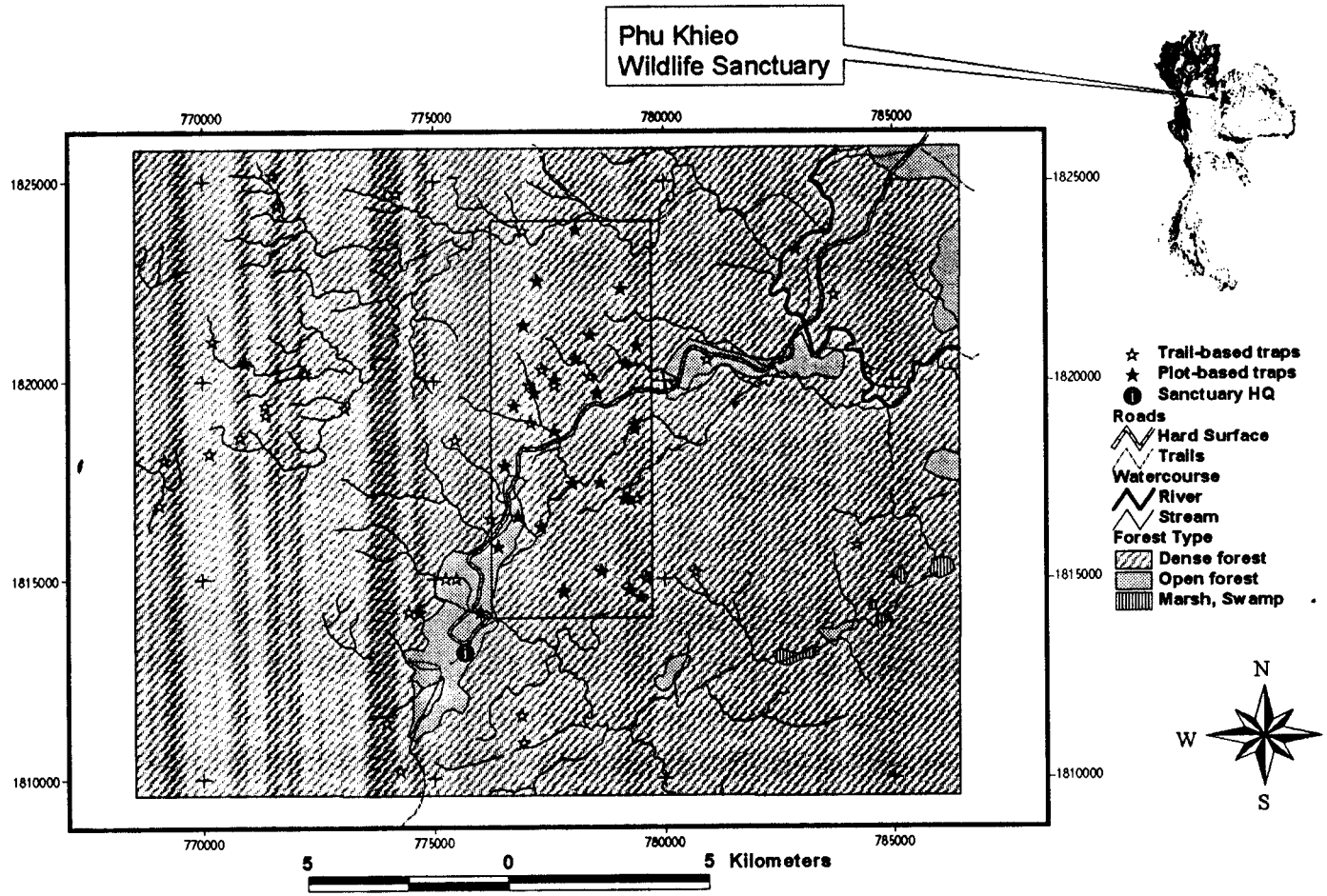

Figure 1. Location of study area and camera-trap sampling locations, Phu Khieo Wildlife Sanctuary, Chaiyaphum Province, Thailand

METHODS

Large mammals of Asian forests are often difficult to observe because they are rare, nocturnal or shy of humans (LEKAGUL AND MCNEELY, 1988; VAN SCHAIK AND CRIFFITHS 1996). For example, tigers have large home ranges of 10–400 km^2 (MIQUELLE *ET AL.*, 1999; SMITH *ET AL.*, 1987), are cryptic and difficult to observe (SCHALLER, 1967), and naturally occur at low density (CARBONE *ET AL.*, 2001). Therefore special methods and approaches are required to determine the status of tigers and other large mammals in their habitats.

Interview Surveys

To determine the broad pattern of occurrence of tigers, sanctuary rangers and guards at 25 substations around the sanctuary were interviewed during 11–13 June 1998. Interview surveys have been used to gather indirect information on the presence-absence of tigers and other rare wildlife species elsewhere in Asia (DUCKWORTH *ET AL.*, 1994; RABINOWITZ, 1993; RABINOWITZ *ET AL.*, 1995). Rangers were asked for information on recent (<5 years) encounters of tigers or tiger sign, and seven species or groups of mammals that are potential prey items for tigers. Rangers were asked to suggest the perceived threats to tigers and tiger prey. Other than direct sightings, it is difficult to resolve differences between tracks and sign of tigers and leopards (DUCKWORTH & HEDGES, 1998). This can sometimes lead to erroneous conclusions about the conservation status of tigers (LYNAM *ET AL.*, 1999). Tracks with total length ≥120 mm or pad width ≥7 cm, and scat (3.5 cm in diameter are generally considered to be indicative of tigers (A. J. Lynam, A. Rabinowitz & R. K. Laidlaw, unpublished data; DUCKWORTH & HEDGES, 1998; CUTTER *ET AL.*, 1999). However, rangers rarely measure track and sign so that reports of tigers based on indirect observations may indicate presence of either tiger or Asiatic leopard.

Sign Surveys

Direct surveys for tigers were done using two approaches. Firstly, presence-absence of tigers and tiger prey species was determined by searching for track and sign along animal trails, saltlicks and waterholes during the course of antipoaching patrols within the sanctuary. The patrols were carried out by 3 teams of 10 sanctuary rangers who had received basic training in the interpretation of wildlife sign. Track length and width were taken on all felid tracks. Tigers were identified by tracks ≥12 cm in length. The patrols were carried out during October 1997 to September 1998. Locations where mammal sign was encountered were recorded with a Global Positioning System (GPS) device capable of resolving position information beneath tree canopies, accurate to ± 100 m* (Garmin 12XL, Garmin Corporation, Kansas USA).

Camera-trap Study

Interviews and sign surveys suggested where tigers were likely to be present in the sanctuary. Passive infrared-based camera-traps (Camtrakker™, Camtrak South Inc., Georgia USA) and active infrared camera-traps (Trailmaster™, Goodson Associates, Kansas USA) were used into confirm presence-absence of tigers in the area where most reports of tigers were concentrated, and to obtain relative abundance information for other large mammals. Passive infrared camera-traps emit an infrared light source that detects a differential in motion and body heat. When warm-blooded animals cross in front of the beam this causes the camera to trigger and take a flash photograph. Active infrared traps record wildlife traffic when a narrow beam is broken by passing animals. Camera-traps have been successfully used to detect tigers (KARANTH, 1995) and other cryptic fauna in tropical forests (GRIFFITHS & VAN SCHAIK, 1993; SEYDACK, 1984).

Two survey designs using camera-traps were employed at Phu Khieo. In both cases, the primary intention was to gain information on where tigers were moving in the area, and to generate an index of tiger "traffic" passing through the area. First, camera-traps were deliberately placed on trails and roads where sign of tigers, large cats or their prey species were recorded. We refer to this as the trail-based survey design. Traps were placed across an approximately 200 km^2 area north of the sanctuary headquarters between 2 December 1997 and 22 January 1999. Traps were left for 30 days, set to operate 24 h per day, and occasionally checked during this period to replace film or batteries.

In the second design, an intensive survey for tigers and tiger prey was done inside a 4 km x 10 km study plot in the center of the sanctuary, inside the larger survey area. We refer to this as the plot-based survey design. A 40-km^2 plot size was used because this study was part of a Thailand wide field program to gain comparative information on tigers across forested landscapes, and this was the standard plot size adopted for the program. The UTM coordinates of the plot corners were 776000 1824000, 780000 1824000, 776000 1814000, 780000 1814000. Camera-traps were placed in a systematic fashion inside the plot. Twenty camera-traps were positioned in alternate 1-km^2 grid blocks within the plot. In each of the 20 grid squares, a single camera-trap was positioned along a road, trail, or dry streambed where sign of tiger or tiger prey species was detected. Cameras were attached to trees with steel cycle locks 40 cm above the ground, 4 m from the line of travel, and angled at 10–30 degrees to the trail. Traps were left for 30–35 days and set to 24-h operation as before.

Because the stripe patterns of tigers are unique to an individual (SCHALLER, 1967) but are different on left and right sides, camera-trap photographs of both sides of an animal must be used to distinguish it from most other tigers (KARANTH, 1995). While specific methods are available for estimating tiger density from double-sided camera-trap designs (KARANTH, 1995). this was not the purpose of this study. However, to gain information on the minimum number of tigers known to be alive (MNKA) inside the survey area, pairs of camera-traps were placed on opposite sides of animal trails, staggered by 2–3 m at locations where experienced field staff considered tigers likely to be present. These "checkpoint" arrangements were established to gain double-sided photographs of tigers.

In summary, the surveys obtained three types of information: i) an index of traffic of tigers and other large mammal species, i.e. capture rate = no. captures/100 trap-nights; ii) minimum numbers of tigers known alive (MNKA); and iii) ranges of individual tigers from

linking outermost points of locations where tigers were captured in camera-traps or identifiable from tracks and sign.

RESULTS

Interview Surveys

From interviews of 24 Royal Forest Department staff at 19 guard stations, reliable reports of tiger sightings were at Huay Bong Hai 7 km N of HQ, in 1983, and in the Thung Kamang area in 1987. Large cat tracks were reported by 17 guards on 24 occasions; six times from Thung Kamang, 2 km SW of the HQ (1987–1997), five times at Salaprom Substation, 12 km NW of HQ (1979–1996), and three times at Lam Saphung in the SE of the sanctuary (1988 and 1996). Near the boundary of the sanctuary at the escarpment, large cat tracks were reported twice at Pa Krop (1987 and 1998), Pa Phu King (1992 and 1996), Pa Lum Chi (1995 and 1998), and once at Pa Bueng Waeng (1997), Pa Prom Song (1996), Pa Gow Noi (1997), and Huai Kum (1994). Sambar carcasses reported to be killed by tiger were found three times; twice at Pa Lum Prom (1996), once at Pa Phu King (1997). A large cat scrape was encountered at Pa Phu King in 1996. Collectively, information from interview surveys suggests that large cats (tigers and leopards) were widespread across the sanctuary in the recent past (<5 years)

Camera-trapping Success

Trail-based survey

Data could be interpreted from 43 camera-traps established on trails, yielding 470 photographic records for a total of 612 camera-trap nights of sampling effort for an average of 1.3 nights per record. Traps were set by sanctuary staff who were using camera-traps for the first time. They experimented with locating traps in a variety of situations, and moved them frequently, averaging 14.2 ± 1.6 nights of sampling effort per trap. Thus a large number of experimental photographs were taken that could not be interpreted (Table 1). Twenty species of large mammal, 4 species of large birds, and 1 unidentified small mammal species were recorded (Figure 2). Three photorecords (0.5 captures/100 trap-nights) of a single tiger were taken at a rate of 204 nights per tiger photograph. The five most frequently trapped species or groups were red muntjac (*Muntiacus muntjak*—6.4 captures/100 trap-nights), followed by large Indian civet (*Viverra zibetha*—3.6 captures/100 trap-nights), large birds (3.3 captures/100 trap-nights), Asian elephant (*Elephas maximus*—2.9 captures/100 trap-nights), and wild boar (*Sus scrofa*—1.8 captures/100 trap-nights). Asian wild dog (*Cuon alpinus*—1.3 captures/100 trap-nights) was the most abundant carnivore. Large birds recorded in camera-traps were Siamese fireback (*Lophura diardi*), silver pheasant (*Lophura nycthemera*), red junglefowl (*Gallus gallus*), and coral-billed ground cuckoo (*Carpococcyx renauldi*).

Table 1. Records from camera-trapping at Phu Khieo Wildlife Sanctuary

	Trail-based survey (612 trap-nights)	Plot-based survey (1,274 trap-nights)
Animals	189 (40%)	279 (63%)
Humans	37 (8%)	48 (11%)
Unidentified	19 (4%)	0 (0%)
Failures	225 (48%)	119 (26%)
Totals	470	446

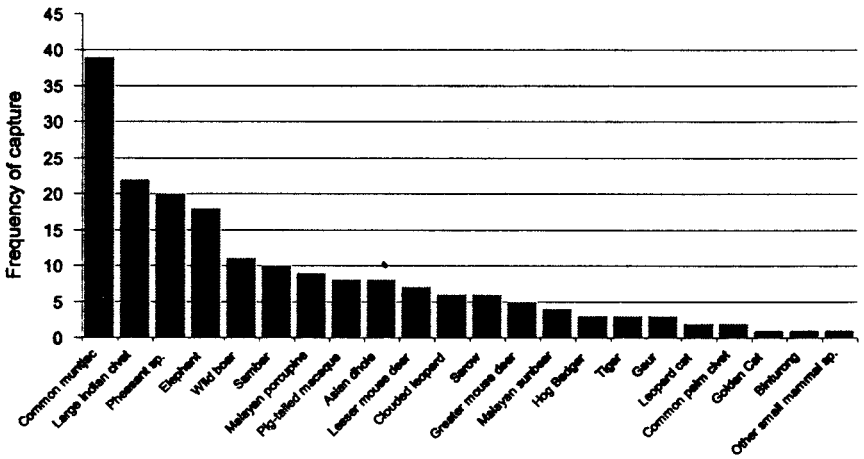

Figure 2. Relative abundance of large mammals at Phu Khieo Wildlife Sanctuary—trail-based survey

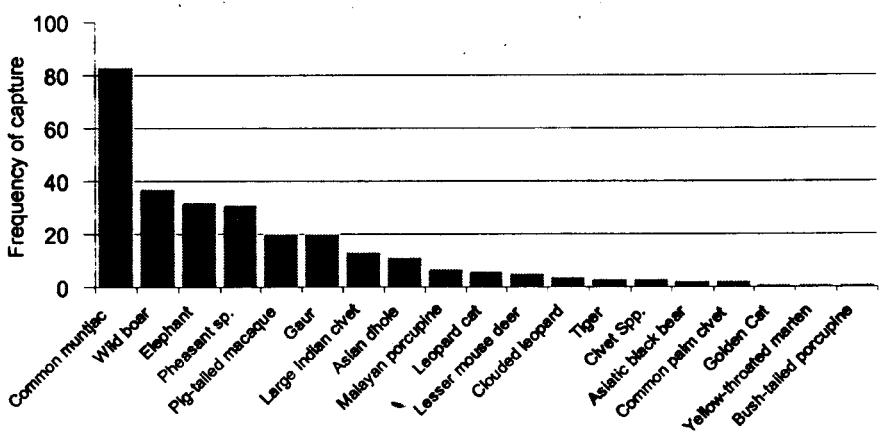

Figure 3. Relative abundance of large mammals at Phu Khieo Wildlife Sanctuary—plot-based survey

Plot-based survey

Two trapping sessions were conducted in the 40-km^2 plot; the first between 6 May and 19 June 1998, the second from 15 June to 27 July 1998. During the first session, 28 camera-traps were established at 24 locations within the plot. This included four pairs of camera-traps set in "checkpoint" arrangements on suspected tiger travel routes. Traps were in operation for 32.2 ± 1.7 nights. No tigers were recorded during this first round of trapping so a second round of trapping was attempted. During the second round, 20 traps were set but no checkpoints were used. Traps were in operation for 26.8 ± 3.2 nights.

From the combined first and second rounds of trapping, a total of 446 records were taken from 1,274 camera-trap nights of trapping for an average of 2.9 nights per record. Eighteen species of large mammal and 4 large bird species (*Lophura diardi, Lophura nycthemera, Gallus gallus*, and *Carpococcyx renauldi*) were recorded (Figure 3). Three photorecords of tiger were taken for an average of 425 nights per tiger photograph. Inspecting the stripe patterns revealed the photos were of a single individual tiger, the same individual recorded during the trail-based survey. *M. muntjak, E. maximus, S. scrofa*, large birds and pig-tailed macaque (*Macaca nemestrina*) were the most frequently trapped animals. Asian wild dog was again the most frequently recorded carnivore in camera-traps (0.9 captures/ 100 trap-nights).

Tiger Ranging Patterns

A total of five camera-trap records of one individual tiger were made from trail-based and plot-based camera-trapping from 1,886 trap-nights of sampling. This individual was caught by camera-traps at a rate of 377 nights per capture. During the foot survey/patrols, tracks suspected to be of this particular tiger were recorded at nine locations (mean length = 119 mm, mean width = 118 mm), and suspected tiger scat was recorded at a further two locations (Figure 4). Connecting the outermost points of observations of the tiger from camera-traps, tracks and scats gives a minimum convex polygon that describes the animal's minimum home range. The estimated size of the minimum home range was 78 km^2.

Association of Tigers with other Large Mammals

To assess whether tigers were associated with certain groups of large mammal species, a multiple response permutation procedure test (MRPP) (ZIMMERMAN *ET AL.*, 1985) was used to compare species compositions at camera-trap locations where tigers were recorded, with locations where tigers were not recorded. Data from the plot-based survey was used in the analysis. Species compositions were significantly different at places with and without tigers ($p<0.05$, MRPP test) suggesting that tigers were associated with a particular assemblage of mammals that was different from the assemblage where tigers were not found.

To better understand what this tiger specific mammal assemblage was, an analysis of potential indicator species was performed (DUFRENE, 1997). Randomizations of the numbers of captures of species at locations with and without tigers were done to test which species were associated with tigers. Tigers were more likely to occur in the presence of two species, wild boar and red muntjac, and less likely to occur without them ($p<0.05$).

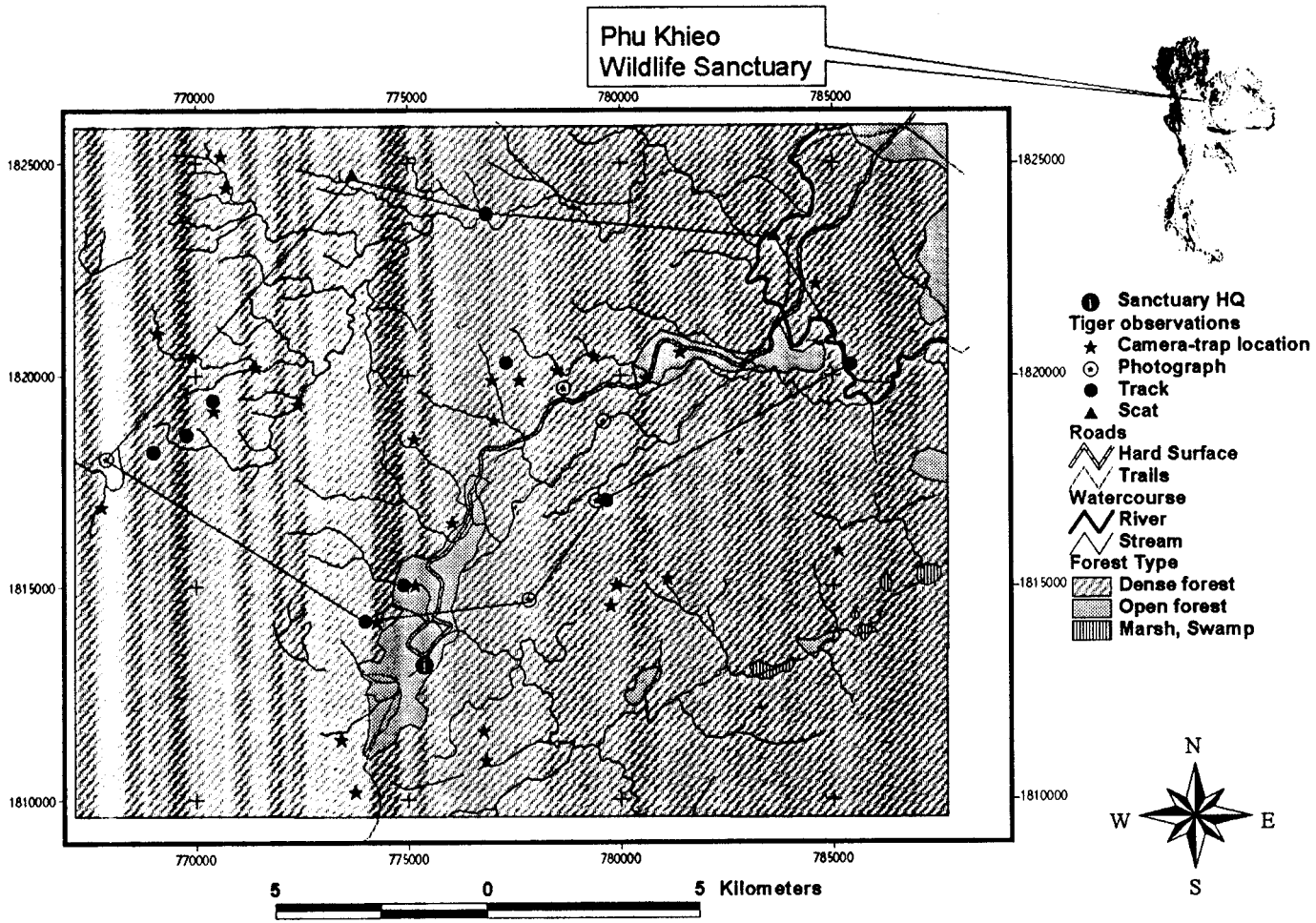

Figure 4. Distribution of tiger observations and minimum home range (plot based camera-trap locations omitted for clarity)

DISCUSSION

In considering the viability of populations of large mammals in Mainland Southeast Asia's fragmented landscapes, relatively large remnants of forested habitat that are not internally fragmented by roads and other human infrastructure, and maintain connections to other forests, are likely to best preserve mammal assemblages. This is because species such as tiger have large homes ranges—50 to 120 km^2 in size (FRANKLIN *ET AL.*, 1999; RABINOWITZ, 1989) and move distances of 20 km or more a night in search of prey (MCDOUGAL, 1996). An Asian elephant herd may range annually over areas of 50–500 km^2 (FERNANDO, 1997). Wild cattle such as gaur have core ranges of at least 100 km^2, and two or more herds of wild cattle may require areas over 2,000 km^2 in size (SRIKOSAMATARA & SUTEETHORN, 1995; DUCKWORTH & HEDGES, 1998). So large mammals require areas in the hundreds or thousands of km^2 for their populations to be demographically viable.

However, in order to maintain evolutionary important levels of genetic diversity within subpopulations, effective population sizes of the order of several hundred individuals need to be maintained (LANDE & BARROWCLOUGH, 1987). BARBAULT & SASTRAPRADJA (1995) suggest the number should be at least 300 females. Large areas will be required to support this number of tigers. For example, female tigers in Indonesia maintain home ranges of 50–70 km^2 (FRANKLIN *ET AL.*, 1999), so a minimum area of 15,000 km^2 would be required to ensure genetic viability in the longer term. Only one of 19 protected forest complexes (Western Forest Complex) reaches this size in Thailand (PRAYURASIDDHI *ET AL.*, 1999). Clearly remnant populations of tigers in the Western Isan Forest Complex and other fragmented habitats must be experiencing some level of genetic inbreeding

Status and Viability of Tigers in the Phu Khieo–Nam Nao Forest Complex

Six large forest complexes in Thailand potentially support demographically viable populations of large mammals, including tigers (WIKRAMANAYAKE *ET AL.*, 1998). These Level I Tiger Conservation Units (TCU's) comprise large, relatively intact complexes of forest, and adjacent lands. Phu Khieo Wildlife Sanctuary is at the center of one of the Level I TCU's (# 10) (WIKRAMANAYAKE *ET AL.*, 1998).

Apart from Sumatran rhinoceros (*Dicerorhinus sumatrensis*) and banteng (*Bos javanicus*), both of which appear to have been extirpated (MCNEELY & LAURIE, 1977), Phu Khieo supports an essentially intact assemblage of ground-dwelling large mammals. Given the richness of large mammals (24 species), the sanctuary contains high quality habitat for tigers in terms of available prey.

It is tempting to contemplate the size of the tiger population at Phu Khieo. Assuming densities of 1 tiger/67 km^2 for high quality habitat, and assuming even densities across available habitat, SMITH *ET AL.* (1999) estimated a potential population of 38 tigers for the Phu Khieo – Nam Nao forest block. Considering the effects of poaching and forest encroachment that reduce the potential to a realized population, RABINOWITZ (1993) estimated 20 tigers for the same area, with 12 tigers for Phu Khieo.

The results of this study do not lend themselves to estimating numbers of tigers in the sanctuary. The most that can be said about the data is that tigers occur at a density of 1 tiger/78 km^2 in the area of Phu Khieo where regular monthly antipoaching patrols are conducted. There are two reasons why it is not possible to extrapolate this density to

estimate the tiger population in the sanctuary. Firstly, the density estimate is based on a sample size of 1, as no other evidence of tigers was recorded from the approximately 300–km^2 study area. Secondly, tiger density is likely to vary across the sanctuary. For example, while tigers were recently reported from areas close to the sanctuary perimeter (this study; HORATA & KREETIYUTANONT, 1997), incursions by poachers are more frequent there (K. Kreetiyutanont, pers. comm.), so that hunting pressure on tigers and their prey species should be more intense and tiger densities should be reduced. Furthermore, given the magnitude of the survey effort mounted here to find just one tiger in one part of the forest complex (1,886 camera-trap-nights), and the trapping effort necessary to develop density estimates from mark-recapture models (KARANTH, 1995), it would take a mammoth investment of resources to determine with some degree of confidence, a reliable population estimate for the sanctuary, let alone the entire forest complex.

Regardless of whether the true population size for tigers is 1, 12 or even 38, the Phu Khieo tiger population is not genetically viable in the longer term, and in the shorter term the species will only persist with appropriate management intervention. In order to prescribe management solutions, the threats to tigers and their habitats and prey species, rather than the number of tigers remaining, need to be considered.

Status of other Large Mammals

A relatively rich and intact assemblage of mammal species exists at Phu Khieo. Twenty-four species of large ground-dwelling or ground-frequenting mammals, including tigers, were recorded during the survey. Some of the more common species (red muntjac, wild boar, gaur, porcupine, macaques) are potential tiger prey species (RABINOWITZ, 1989). Gaur tracks and dung were regularly encountered during the surveys, and the animals themselves were occasionally seen. Although banteng appear to have been extirpated from Phu Khieo in the last 15 years due to intense poaching (SRIKOSAMATARA, 1995), several small herds of gaur persist. Sambar was not found in the plot-based survey but was recorded from trail-based camera-traps further to the west of the plot. Sambar also frequent grasslands and semi-natural clearings near the sanctuary headquarters.

Red muntjac, wild boar, pig-tailed macaque, pheasants and Malayan porcupine were abundant in the study area. Two potential prey species, wild boar and red muntjac, were indicators of the presence of tigers. Tigers were more likely to be found in places with these two species, and less likely to occur without them which suggests that wild boar and muntjac might be important food items for tigers, and possibly also for Asian wild dog. The discovery of a carcass of a wild dog in the study area on July 25th 1998, apparently killed by a tiger, is evidence that wild dogs may be naturally competing with tigers for food at Phu Khieo.

Threats to Tigers and Possible Management Solutions

Large mammal populations at Phu Khieo and other forests in Petchabun and Chaiyaphum Provinces have been subject to human poaching pressure for at least 100 years. In the early 1900s native Kha Dong Luang people hunted rhinos, gaur, deer and wild boar (SEIDENFADEN, 1967). Thirty to 50 years ago, tigers were targeted by professional poachers who supported themselves by killing small game (IAMKRASIN, 1994; 1996). By the time the sanctuary was

gazetted in 1973, rhinos, primates, and large birds were still being hunted, and local communities whose source of meat came from hunting wild animals were resident at Thung Kamang, where the sanctuary headquarters is today (MCNEELY & CRONIN, 1972). The presence of Meo insurgents in the forest interior kept out local hunters but these insurgents probably also hunted.

Camera-traps do not discriminate—they recorded the movements of both animals and humans in the study areas. In the plot-based survey, 11 percent of records were human traffic, but only 2 percent of these were of poachers or collectors, the rest being legitimate visitors to the sanctuary. However, 8 percent of camera-trap records from the trail-based survey were of human traffic, half of which were poachers and collectors of non-timber forest products (NTFPs), the other human traffic being of sanctuary staff, researchers, tourists and vehicles. Interview surveys in villages surrounding Phu Khieo revealed that middlemen purchase rats, deer, primates and birds directly from villagers who trap and hunt them in and around the sanctuary using a variety of methods (N. Magnus, personal communication). Poaching is highly organized to accommodate this trade. Villagers are knowledgable of sanctuary patrol procedures so they are able to evade detection. Tigers may be directly threatened by poachers seeking live and dead tigers for city-based markets (K. Kreetiyutanont, personal communication)

In addition, tigers and other carnivores are threatened indirectly by the poaching of prey species. The minimum range of the tiger at Phu Khieo was twice that estimated in Huai Kha Khaeng in western Thailand (RABINOWITZ, 1989) suggesting a lower prey density with wider movements required to find prey. Habitat differences may partly explain this phenomenon, with the relatively drier and diverse forests of the Western Forest Complex supporting higher densities of ungulates than the evergreen forests of Phu Khieo. However, poaching may also influence prey densities. Two types of poaching of large mammals is done at Phu Khieo: subsistence poaching by aloewood (*Aquilaria* spp) collectors, and commercial poaching for local markets. This is similar to the situation in Khao Yai National Park (WCS/WILD AID, 1999) where hundreds of local villagers daily poach and collect aloewood and the tiger populaton has been decimated (A. J. Lynam, unpublished data). While physical disturbance from the sheer numbers of people entering Khao Yai may disturb tigers and interrupt their normal activity and reproduction, erosion of the prey base by poaching (KARANTH & STITH, 1999) is likely an insidious threat to tigers at Phu Khieo.

A further threat to tigers and other large mammals at Phu Khieo comes from forest conversion and encroachment. A reservoir at the north perimeter of the sanctuary provides a convenient access point to the forest for poachers. Forest near the southern boundary of Phu Khieo Wildlife Sanctuary support tiger, elephant, Asiatic wild dog, bear and ungulates but wildlife populations are threatened by a proposed irrigation project in the Lam Sapung watershed. Despite claims that the proposed project will improve wildlife habitats, scientific evidence suggests that reservoirs benefit only the most ecologically tolerant species (LYNAM & BILLICK, 1999) but lead to the rapid extinction of others (LYNAM, 1996; LYNAM, 1997). Consequently, such projects should be relocated outside the sanctuary.

Conservation Recommendations

1. Extend survey efforts to poorly known peripheral areas of Phu Khieo, and to protected areas adjacent to the sanctuary where poaching and forest encroachment threaten tiger and tiger prey populations;

2. Establish a monitoring program, to determine the seasonal and spatial fluctuations in abundances of tiger prey species, and the behavior patterns of tigers and other carnivores in the sanctuary;
3. Train sanctuary rangers and guards in antipoaching and patrolling techniques, boost their personal esteem, and reduce the chances of injury or death. This training should be done by agencies that specialize in wildlife security, and by Thai paramilitary forces (Border Patrol Police or Army rangers) since their responsibilities, protecting watersheds and forests, are similar to those of forest rangers;
4. Increase patrolling in areas near the boundary of the sanctuary where hunting and encroachment are greatest;
5. Avoid development projects in areas of high diversity for large mammals, including the Lam Saphung watershed;
6. Expand wildlife and biodiversity awareness programs that have been initiated in local communities. These include special camps inside the sanctuary and at nearby Huai Kum Education Centre, for local school children, and a captive breeding centre;
7. Conduct long term research on carnivore community ecology, especially competitive relations among larger species

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