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Wild Asian elephant *Elephas maximus* population in Salakpra Wildlife Sanctuary, Thailand

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ABSTRACT: The population of wild Asian elephants *Elephas maximus* is declining worldwide; therefore, understanding the dynamics of the remaining population is critical for effective conservation. We monitored the population and distribution of elephants in Salakpra Wildlife Sanctuary, Thailand between May 2010 and March 2011. Using 32 camera trap locations and 1391 trap nights, we recorded 882 elephant photos. A total of 180 individuals were identified in the photos and classified as follows: 55 adult males, 60 adult females, 11 sub-adult males, 17 sub-adult females, 18 juveniles, and 19 calves. The age structure ratio (based on adult females) was 0.9 : 1.0 : 0.2 : 0.3 : 0.3 : 0.4, and the ratio of reproductive ability between adult females, juveniles, and calves was 1.0 : 0.3 : 0.3. The ratio between adult females and infants was highest in areas containing a high concentration of salt licks, which could indicate that salt licks are a keystone resource for wild Asian elephants.

KEY WORDS: Wild Asian elephant · Age structure · Habitat management · Conservation · Population monitoring

INTRODUCTION

The continuous destruction of forested areas in Asia has had a negative impact on wildlife, particularly Asian elephants *Elephas maximus*. As a consequence, the population of wild elephants has declined from estimates of 41 410 to 52 345 individuals in 2003 (Sukumar 2003) to between 25 600 and 32 750 individuals in 2006 (WWF 2006). Elephants are large mammals that live in herds and have a pastoral lifestyle; these are characteristics that affect the land as well as other animal species (Sarker & Røskaft 2010). Currently, Asian elephants are classified as Endangered in all countries where the species occurs (IUCN 2013). Thailand is the center of wild elephant distribution in Southeast Asia, and its borders represent potentially important transboundary areas linking the elephant populations of Thailand with those of the neighboring countries. In Thailand, population estimates for elephants range from 3000 to 3500 individuals (Srikrachang 2003). Considered an important umbrella, keystone, and seed-dispersing species (Campos-Arceiz & Blake 2011), elephants may act as ecosystem engineers that support the biodiversity of the tropical rainforest by maintaining habitat gaps. However, the continuing loss of primary forests has reduced their ecosystem engineer function (Matsubayashi et al. 2006).

Camera traps can be effective tools for the documentation of wildlife (Rowcliffe & Carbone 2008). This technology is an unobtrusive method for animal observation in any habitat (Silveira et al. 2003) and has been successfully used for individual identification of large mammal species (Lyra-Jorge et al. 2008). For example, camera traps appropriately estimated (with a small error) African elephant populations

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using shoulder height as an indicator of age (Della Rocca 2007). Similarly, Varma et al. (2006) used camera traps to study the population dynamics of elephants in southern India.

In Thailand, elephants are distributed within protected areas, but their population status is not fully known (Srikrachang 2003). Salakpra Wildlife Sanctuary is one of the protected areas in the Western Forest Complex. The estimated elephant population ranges from 150 to 200 individuals (Srikrachang 2003). There has been rapid economic development within the Western Forest Complex, such as the construction of the Srinakarin and Thathungna Dams, roads, human settlements and agricultural activities, and the resulting habitat fragmentation has led to isolated populations of elephants (Pattanavibool et al. 2004). Habitat loss and fragmentation can lead to loss of genetic diversity (Kongrit et al. 2008) and reduce the population's carrying capacity potential. Although the size of the elephant population in Salakpra Wildlife Sanctuary has been evaluated (Srikrachang 2003), to our knowledge no studies have examined the population structure. In this study, we aimed to estimate the population size, age structure, and distribution of elephants in Salakpra Wildlife Sanctuary using camera traps. We also provide practical guidelines for the management of the elephants at that site.

MATERIALS AND METHODS

Study area

The study was carried out in the Salakpra Wildlife Sanctuary (14° 8′ 37.09″ N, 99° 20′ 33.514″ E), an area of ~860 km^2 in Mueang, Bo Phloi, Si Sawat, and Nong Prue districts, Kanchanaburi Province, Thailand (Fig. 1). Elevation in the area ranges between 700 and 1000 m above sea level. The average temperature is 28°C, with an average rainfall of 1071 mm yr^{-1}. The area consists of mixed deciduous forest (60%), dry dipterocarp forest (30%), and disturbed areas (10%). The dominant plant species in the Sanctuary are *Lagerstroemia tomentosa*, *Terminalia alata*, *T. triptera*, *T. bellirica*, and *Afzelia xylocarpa* (Salakpra Wildlife Sanctuary 2011).

Camera trap survey

A preliminary survey for elephant signs was carried out in each of the study zones by walking, examining all available trails, water sources, natural licks, and forest types. All elephant signs were plotted in a Geographic Information System (GIS) along with associated details of elevation, slope, and forest type (Wang

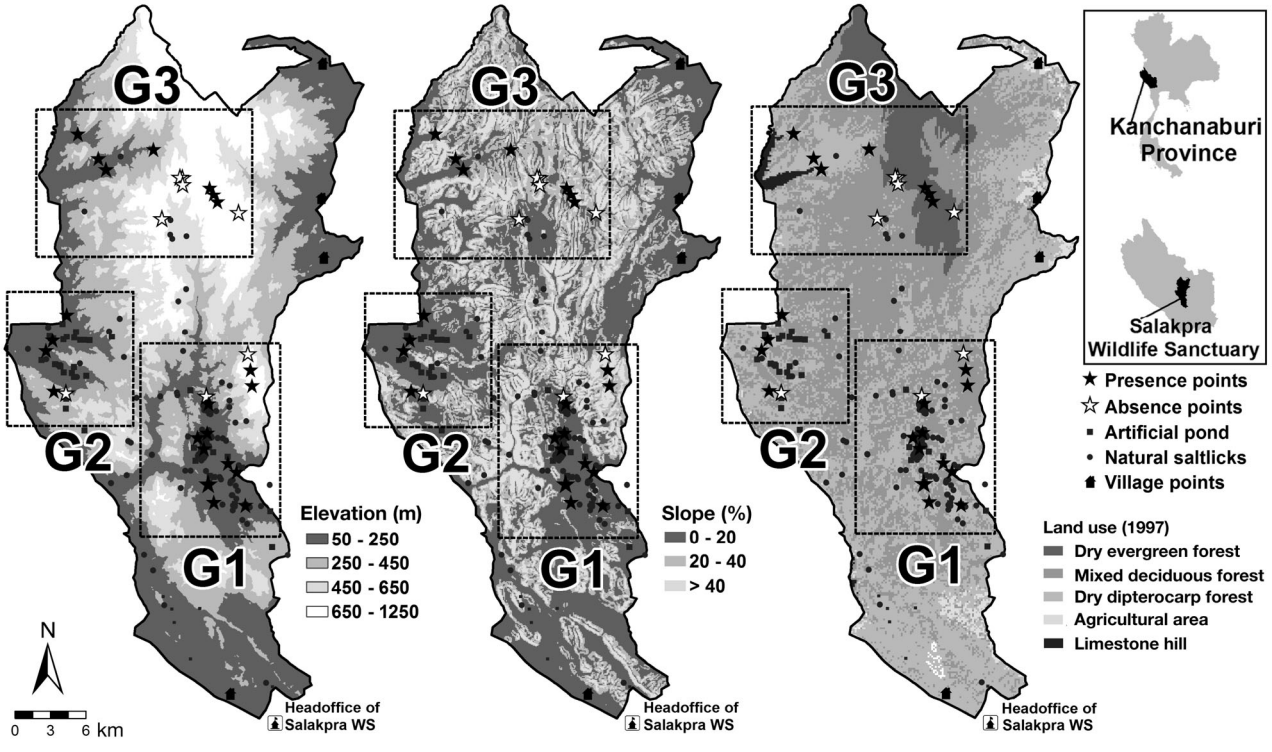

Fig. 1. Average elevation, slope, forest type and the occurrence of wild Asian elephants *Elephas maximus* in the Salakpra Wildlife Sanctuary, Thailand. G1: Thung Salakpra; G2: Mong Krathae; G3: Huai Mae Lamun

& Macdonald 2009). Camera trap locations were selected based on where elephant tracks were detected during the preliminary survey. For example, during the dry season elephants tend to be concentrated near water sources, and thus large water sources are suitable for direct counts of elephant populations (Wanghongsa 2004). Therefore, water sources within our study site were a major location for camera trap placement (Varma et al. 2006), followed by natural licks and wildlife trails (Rovero & Marshall 2009), which are also frequently visited by elephants.

A total of 12 MOULTRIE® camera traps (model I40; Moultrie Feeders) were rotated among 32 trapping stations, with locations changed every 15 d. Each trap station was set with 2 cameras facing each other, positioned to photograph both asymmetrical flanks of the elephant to ensure positive identification (Soisalo & Cavalcanti 2006). Camera traps were mounted on trees approximately 0.75 m above the ground (Rowcliffe et al. 2008), with distances between traps ranging from 1 to 3 km. Camera traps operated continuously for 24 h with a shooting interval of 1 min. The resolution of the pictures was 1648 × 1236 pixels. Camera ID, time, date, and temperature were also recorded for each exposure and were stamped on the photographs.

Population density

The photographs obtained from the camera traps were used to identify and record the location, forest type, date, time, sex, and age of each animal. We also recorded obvious distinguishing morphological features and basic body dimensions to differentiate among individuals (Goswami et al. 2012). Only photographs with sufficient quality, clarity, and position of the elephant in the frame were used for identification (Varma et al. 2006). Here, quality refers to how usable a picture is for age and sex classification; clarity indicates whether the elephant was 'captured' in good light, the flash reached the object, and the picture is in focus and not over or under-exposed; and position refers to the occurrence of the elephant within an 'optimal distance' from the camera, and whether all or most of the head and tail of of the individuals is visible. Thus, even if a picture is of good quality, the information captured in the picture may not be adequate and it would therefore not be usable. Elephants in the photographs were classified as adults, sub-adults, juveniles, or calves using approximate height as recommended by Arivazhagan & Sukumar (2008) and Ashokkumar et al. (2010). Adults and sub-adults were further classified as male or female by their distinctive secondary sex characteristics; these characteristics were not apparent in the juveniles and calves. We defined the age structure as the ratio between adult males, adult females, sub-adult males, sub-adult females, juveniles, and calves; reproductive ability was the ratio of age structure between adult females (including sub-adult females), juveniles, and calves. Male elephants living outside the herd were classified as solitary males.

Capture history was used to generate capture frequencies of identified individuals. Data were recorded in an x matrix consisting of i elephants in rows and t trapping occasions in columns, assuming a value of either '0' if the individual was not photographed or a '1' if it was photographed. The capture histories of individual elephants were used in the framework of capture-recapture theory to estimate capture probabilities and population size using the computer program MARK (White & Burnham 1999). Based on the capture-recapture analysis, 4 models were distinguished: (1) M(0), which assumes that there is no heterogeneity in capture probability and that capture probability is constant across capture occasions, (2) M(t), which allows capture probabilities to vary among capture occasions but assumes no heterogeneity in capture probability, (3) M(h), which allows for heterogeneity in capture probabilities among individuals, and (4) M(b), which allows for the capture probabilities of individuals to be a function of their previous capture history (see Table 1). Determined deviance information criterion (DIC) values ranged between 21.30 and 21.73. Based on White et al. (1982), the model with the lowest DIC should be selected as the population estimate.

The population density of elephants was calculated as follows:

$$\text{Crude density (ind. km}^{-2}) = \text{total no. ind. / total area (km}^2)$$

while the relative abundance index (RAI) for elephants in each zone was calculated as:

$$\text{RAI} = (\text{no. independent photographs at all locations} \times 100) / \text{total no. trap-nights}$$

RAI increased when elephants were at high densities.

Habitat use

Habitat utilization was defined as the presence or absence of elephants in the habitat types of all camera trap locations. Average elevation was classified

as lowland (50 to 250 m), foothills (250 to 450 m), mountains (450 to 650 m), and highlands (650 to 1250 m). Slope was classified as 0 to 20%, 20 to 40%, and >40% (Feng et al. 2010). Forest type was classified as mixed deciduous, dry deciduous dipterocarp, or dry evergreen forest (Salakpra Wildlife Sanctuary 2011). Threat factors such as poachers, hunting dogs, and domestic cattle were recorded from the camera trap photos.

The locations of all cameras were recorded using a global positioning system (GPS) unit. Topographic data were obtained from WEFCOM (2004), and ArcView v.12 (ESRI 2007, www.esri.com/index.html) was used to create the maps. Relative frequency (RF), used to estimate the distribution of the elephants, was calculated for all camera trap locations as:

RF = No. camera locations that captured photographs × 100 / total camera locations

Statistical analysis

A 1-way ANOVA was used to compare population structure in different areas. The coefficient of correlation was used to analyze the relationship between the population structure and water sources, natural licks, elevation, slope, forest types, and threat factors using SPSS v.17.0 (SPSS Inc.). Differences between population structure and environmental factors were considered significant at $p < 0.05$.

RESULTS

Population density

A total of 180 individuals were identified from 882 photographs at 23 camera trap sites in Salakpra Wildlife Sanctuary. Based on this information, we determined that the M(*b*) model, which estimated a population size (±SE) of 181.20 ± 1.51 individuals, was the most suitable (Table 1). The crude density of wild Asian elephants in Salakpra Wildlife Sanctuary was 0.21 ind. km^{-2}. The population was classified as consisting of 55 adult males, 60 adult females, 11 sub-adult males, 17 sub-adult females, 18 juveniles, and 19 calves, with a ratio of 0.9 : 1 : 0.2 : 0.3 : 0.3 : 0.4 using the adult female as a reference. The ratio of reproductive ability between adult females (including sub-adult females), juveniles, and calves was 1 : 0.3 : 0.3 ($F = 0.778$, df = 2, $p = 0.46$) (Table 2).

Table 1. Model selection statistics using the closed population estimation model type on wild elephant *Elephas maximus* capture-recapture data from the Salakpra Wildlife Sanctuary, Thailand. For a definition of M(0), M(*t*), M(*h*), and M(*b*) see 'Materials and methods; Population density'. DIC: deviance information criterion; N: population size; SD: standard deviation

Model	DIC	N	SE
M(0)	21.73	181.48	2.12
M(*t*)	21.31	181.57	3.24
M(*h*)	21.45	181.86	2.80
M(*b*)	21.30	181.20	1.51

Distribution

Animals were separated into 3 distinct groups based on camera trap locations (Fig. 1): Group 1, Thung Salakpra, located at the center of the Salakpra Wildlife Sanctuary, contained 123 individuals; Group 2, Mong Krathae, located near Ban Mong Krathae and Ban Koh Buk in the western part of the Salakpra Wildlife Sanctuary consisted of 30 individuals; and Group 3, Huai Mae Lamun, located near Huai Mae Lamun and Huai Mae Plasoi in the northern part of the Sanctuary contained 27 individuals.

Most elephants were found in the lowland areas (50%), while only a solitary male (16%) was found in the highlands. The number of elephants decreased as elevation increased ($r = -0.18$, $p = 0.02$). Elephants were found in all slope types, but their presence decreased as the slope increased ($r = -0.10$, $p = 0.18$).

Table 2. Ratio of age classes and reproductive rate of each geographical group of wild Asian elephants *Elephas maximus* in the Salakpra Wildlife Sanctuary, Thailand, using adult females as a reference. AM: adult male; AF: adult female; SM: sub-adult male; SF: sub-adult female; JU: juvenile; CA: calf

Group	Age structure ratio						Reproductive ratio			*F*	df	p-value
	AM	AF	SM	SF	JU	CA	AF+SF	JU	CA			
Thung Salakpra	0.9	1	0.2	0.2	0.4	0.4	1	0.4	0.4	0.937	10	0.50
Mong Krathae	1.0	1	0.1	0.6	0.2	0.4	1	0.2	0.4	0.944	2	0.40
Huai Mae Lamun	0.8	1	0.1	0.3	0.2	0.1	1	02	0.1	1.590	4	0.21
Total	0.9	1	0.2	0.3	0.3	0.4	1	0.3	0.3	0.778	2	0.46

Table 3. Environmental factors and the occurrence of wild Asian elephants *Elephas maximus* in Salakpra Wildlife Sanctuary, Thailand. Times: no. of times an individual was photographed; gaps indicate data not available

Environmental factor	Presence		Absence		Relative frequency of occurrence (%)	*F*	df	p-value
	Times	Frequency (%)	Times	Frequency (%)				
Habitat use						1.979	2	0.14
Waterholes	7	100	0	–	22			
Natural licks	10	90.9	1	9.1	31			
Trails	6	42.9	8	57.1	19			
Total	23		9					
						r		p-value
Elevation (m)								
50–250	16	94.1	1	5.9	50	–0.18		0.02
250–450	2	50	2	50	6			
450–650	–	–	–	–	–			
650–1250	5	45.5	6	54.5	16			
Total	23		9					
Slope class (%)						–0.10		0.18
0–20	17	85	3	15	53			
20–40	3	60	2	40	9			
>40	3	42.9	4	57.1	9			
Total	23		9					
Forest type								
Mixed deciduous	17	80.9	4	19.1	53			
Dry dipterocarp	3	100	0	0	9			
Dry evergreen	3	37.5	5	62.5	9			
Total	23		9					

With respect to habitat types, salt licks, water sources, and active elephant trails were mainly found in mixed deciduous forest (53%), rather than in dry evergreen forest (9%) or dry deciduous dipterocarp forest (9%) (Table 3, Fig. 1). The use of natural licks, waterholes, and wildlife trails did not differ among habitat types ($F = 1.979$, df = 2, $p = 0.14$).

The RAI of elephants in the entire Salakpra Wildlife Sanctuary was 10.3 captures per 100 trap nights, with a relative frequency of 72% considering all camera trap sites. Elephants obtained the highest relative abundance at waterholes, and the relative frequency was highest in natural licks (Table 4).

Table 4. Relative abundance index (RAI) and relative frequency (RF) of wild Asian elephants *Elephas maximus* in Salakpra Wildlife Sanctuary, Thailand. 'Presence' indicates the no. of traps in which the elephants were photographed

Type	Total (traps)	Presence (traps)	No. trap nights	Encounter rate	RAI	RF
Waterhole	7	7	293	56	19.11	22
Salt lick	11	10	540	67	12.41	31
Wildlife trail	14	6	558	20	3.58	19
Total	32	23	1391	143	10.28	72

DISCUSSION

The Asian elephant population in the Salakpra Wildlife Sanctuary has increased from 20 and 35 individuals in 1987 and 1990, respectively (Dobias 1987, Santiapillai & Jackson 1990) to 180 individuals in 2012 when this study was carried out. These findings are supported by Siripunkaw & Kongrit (2005), who estimated a similar population size for our study area using a DNA analysis. The elephant density found in these studies was similar to that of the Khao Ang Rue Nai Wildlife Sanctuary (Wanghongsa et al. 2006) and the Bardia National Park in Nepal (Flagstad et al. 2012), but lower than in Huai Kha Khaeng Wildlife Sanctuary in Thailand (0.73 ind. km^{-2}) (Sukmasuang 2003). According to the carrying capacity model of Sukumar & Santipiallai (1993), elephant density may reach 0.2 to 0.3 ind. km^{-2}, or 216 individuals in our study area. This may explain why some elephants go outside the Salakpra Wildlife Sanctuary due to the population exceeding the carrying capacity as Wanghongsa et al. (2007) suggested. However, the elephant density of Salakpra Wildlife Sanctuary surpasses the population limit suggested by the model. The number of elephants in Salakpra was also confirmed by closed captures in MARK

(White & Burnham 1999). Due to the short-term period of our study, the population size did not vary between sampling events, and there were no episodes of immigration or emigration.

The population structure of wild Asian elephant in the area consisted of mostly adult individuals, which agrees with the findings of Santiapillai et al. (1984). Obtaining this information was only possible because of the use of camera traps to identify the individuals and to classify their age and sex (see also Varma et al. 2006).

The population also consisted of more adult females than adult males; therefore, the probability of reproduction is high. Overall, the reproductive ratio of wild elephants in Salakpra Wildlife Sanctuary was relatively low compared to the findings of Katugaha et al. (1999) in Ruhuna National Park, Sri Lanka, and Siripunkaw & Kongrit (2005) in our study site from several years prior to the present study. This is probably due to our inclusion of sub-adult females in the reproductive ratio calculation. Conversely, the reproductive ratio of adult females to calves was greater than for elephants in India (Choudhury 1999, Ramesh et al. 2012). This variability in population dynamics likely reflects differences in environmental conditions and carrying capacities between sites (Ramesh et al. 2012), such as salt licks in the Salakpra Wildlife Sanctuary. At any rate, our study shows a trend towards an increasing population of elephants.

Most elephants were found in the flat plains, which is consistent with the findings of other studies (Pradhan & Wegge 2007, Varma 2008, Zhang 2011, Alfred et al. 2012), and also where most waterholes are located (Alfred et al. 2012). Elephants generally avoid feeding or walking in upland areas in order to save energy (Wall et al. 2006). We found that solitary male elephants appeared at higher elevations in dry evergreen forests to avoid conflict with the dominant males in the lowland areas. This finding is similar to that of Steinmetz et al. (2008), who found elephants in the hill evergreen forests above 1000 m in Thung Yai Naresuan Wildlife Sanctuary, Thailand, and that of Wanghongsa et al. (2006), Lin et al. (2008), Varma (2008), and Joshi (2009), who documented elephants in areas up to 1300 m above sea level. We established that elephants in the Salakpra Wildlife Sanctuary mainly used shallow slopes (0 to 20%), a finding similar to other studies (Sukmasuang 2003, Lin et al. 2008). Mixed deciduous forest was the most suitable habitat for elephants in Salakpra Wildlife Sanctuary, since bamboo, a favorite food of elephants, is dominant in the area (Gray & Phan 2011). Large food-plant productivity has been found to be positively related to utilization by wild elephants (Rood et al. 2010), and is a main factor affecting their seasonal movements (Lin et al. 2011).

Elephants were photographed more often at salt licks and waterholes compared to wildlife trails. Asian elephants rely on salt licks for nutrient supplementation (Moe 1993, Klaus & Schmid 1998, Mills & Milewski 2007) and alleviation of gastrointestinal disorders from toxic plant compounds, acidosis, diarrhoea, and endoparasites (Klaus & Schmid 1998, Krishnamani & Mahaney 2000). Most salt licks were located within relative proximity to streams or waterholes within mixed deciduous forest, with those closest to the waterholes being the most frequently visited. The principal factor determining elephants' use of salt licks and waterholes is thought to be the annual rainfall cycle; elephant movements are known to be strongly controlled by water availability, especially during the dry season (Smit et al. 2007, Chamaillé-Jammes et al. 2007, de Beer & van Aarde 2008).

Our research indicates that the basic factors that are important to elephant populations are salt licks, waterholes, and food sources. In order to provide the most effective management of wild elephant populations, the following actions should be considered: (1) maintain shallow permanent waterholes; (2) maintain and monitor effective salt licks, measuring the minerals remaining in them, which will be beneficial for elephants as well as other wildlife; (3) increase potential food sources such as grassland areas and remove invasive exotic plants and weeds; and (4) re-establish food-plant species in disturbed areas.

CONCLUSIONS

Our study suggests that the 3 groups of elephants in the Salakpra Wildlife Sanctuary were distributed according to the presence of the same fundamental features: flat plains, low slopes, areas of mixed deciduous and dry dipterocarp forests (bamboo), waterholes, and salt licks. The RAI of elephants in this study was greater than that in other areas due to the high reproductive ratio. This indicates that the trend for the elephant populations in the Salakpra Wildlife Sanctuary is increasing. However, effective management strategies must be applied to ensure the long-term conservation of this and other Asian elephant populations.

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