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Sumatran elephant ranging behavior in a fragmented rainforest landscape

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Increasingly, habitat fragmentation by agricultural and human development has forced Sumatran elephants (*Elephas maximus sumatranus*) into relatively small areas; yet, there is no information on the movements and home range behaviors of elephants on Sumatra. Using a GPS collar, we estimated the home range sizes of an adult female elephant (one of a herd of 40 to 60) in the Seblat Elephant Conservation Center (SECC), Bengkulu Province of Sumatra in 2007 to 2008. We assessed the level of autocorrelation among elephant locations, and used correlation and logistic regression analyses to examine relationships between elephant movements and monthly rainfall, and elephant locations with the remotely sensed enhanced vegetation index (EVI), and distance to roads and rivers. Overall home range size was 97.4 km^2 for the minimum convex polygon (MCP), and 95.0 km^2 for the 95% fixed kernel (FK), estimator. There were no relationships between average monthly elephant home range sizes or movement distances with rainfall. Distances to rivers and ex-logging roads had little effect on elephant locations, but EVI, an index of canopy photosynthetic capacity, did correspond with elephant locations, occurring predominately in forests with intermediate canopy cover versus closed canopy forests. Consistent food and water availability in the lowland forests of the SECC in combination with high human development surrounding the center probably affect the small home range size.

Key words: *Elephas maximus*, home range, Indonesia, movement, Sumatran elephant.

INTRODUCTION

The Sumatran elephant (*Elephas maximus sumatranus*), one of four Asian elephant subspecies occurring only on the island of Sumatra (Hartl et al., 1996; Fernando et al., 2000; Fleischer et al., 2001), is estimated to number only 2400-2800 (excluding elephants in conservation centers) in 25 fragmented populations (Soehartono et al., 2007). Most populations occur in lowland areas with upwards of 85% of their range outside of protected areas, and all populations are considered vulnerable to continuing habitat loss from large-scale habitat conversion by agriculture, human settlement, illegal logging and forest fires (Hedges et al., 2005; Soehartono et al., 2007; Uryu et al., 2008). Additionally, continuing habitat loss brings elephant populations closer to human settlements, resulting in human-elephant conflict (Sukumar, 1992; Leimgruber et al., 2003; Hedges et al., 2005). These human-elephant conflicts often result in the capture and removal of elephants by the government or poisoning by local people to mitigate the conflict (Hedges et al., 2005).

Current conservation strategies for Sumatran elephants focus on securing elephant habitat and mitigating human-elephant conflict. There is also a critical need to link isolated elephant populations by facilitating elephant movements across the landscape (Soehartono et al., 2007). Developing effective land conservation strategies for elephants, however, is difficult because there is no information on the movements and home range of elephants on Sumatra. Most studies of Asian elephant ranging behaviors have been conducted on Indian elephants (Sukumar, 1989; Desai, 1991; Williams et al.,

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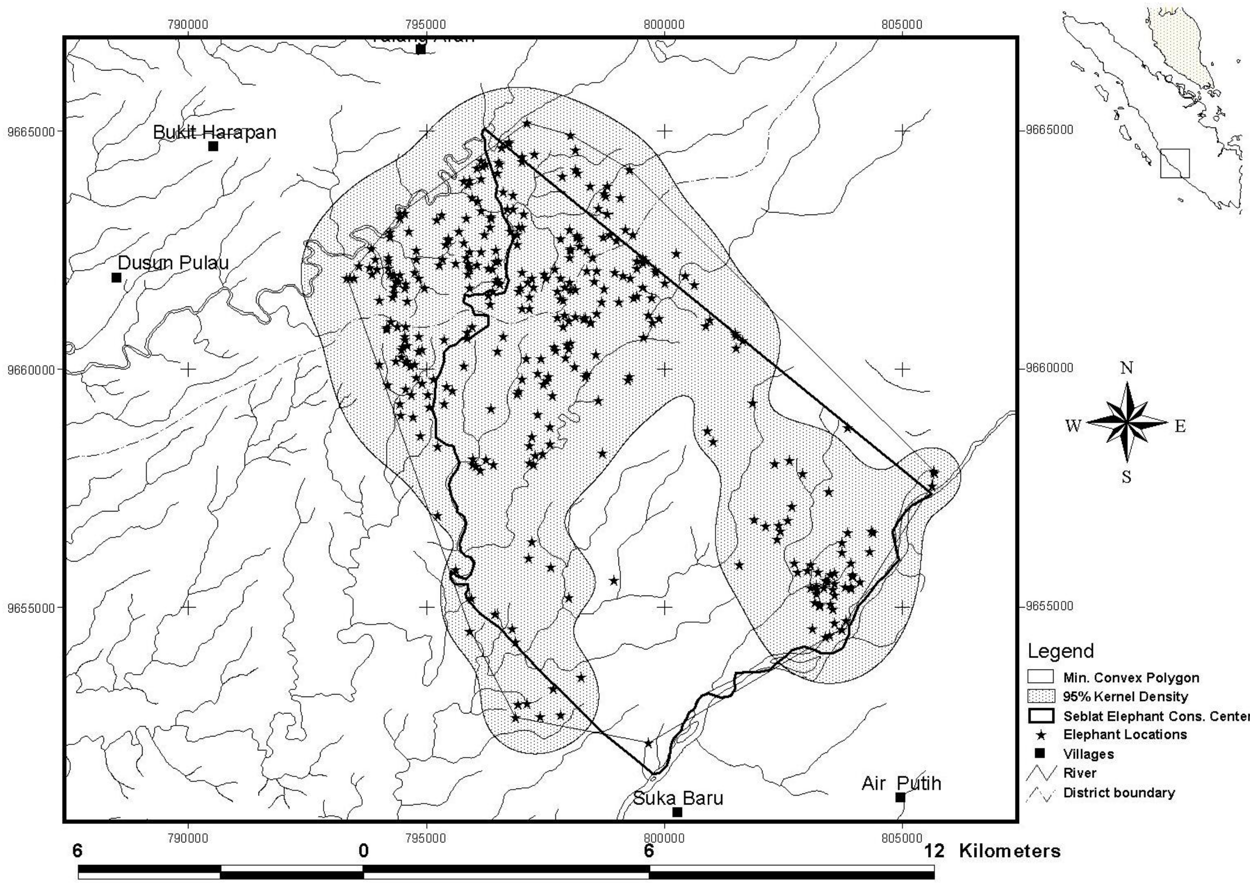

Figure 1. Home ranges [minimum convex polygon estimate (MCP) and fixed kernel density estimate (FKDE) 95% contour] for an adult female elephant, August 2007 to May 2008, Bengkulu Province, Sumatra.

2001). Also, Olivier (1978) provided limited information on elephant movements and home range behaviors from his radio telemetry study in Taman Negara National Park in Malaysia, and Stüwe et al. (1998) reported a home range size of 350 km^2 for a male elephant and 7,000 km^2 for a female elephant from satellite telemetry after translocation to Taman Negara National Park.

The absence of information on Sumatran elephant movements and home range behaviors has hampered development of effective land conservation strategies for elephants on Sumatra. Consequently, land use planning and protected area management in and around elephant habitats remain ineffective. Further, fragmentation of elephant habitats into relatively small areas also complicates elephant conservation programs on Sumatra (Santiapilai and Jackson, 1990; Leimgruber et al., 2003). The purpose of this study was to describe the home range size and movements related to habitat use of a wild female elephant in a lowland rainforest of Sumatra as related to monthly rainfall, a vegetation index, and distance to roads and rivers. Although based on a single individual, movements of this GPS-collared elephant likely represent movements of the only breeding herd in the area, and provide the only information on elephant movements in Sumatra.

Study area

The study was conducted in the Bengkulu Province on the west coast of Sumatra and included the Seblat Elephant Conservation Center (SECC) (Lat. 03° 03’12” - 03°09’24” S, Long. 101° 39’18” - 101° 44’50” E) and surrounding forested and developed areas (335.6 km^2; Figure 1). Annual rainfall typically exceeds 3,000 mm (data collected at SECC); the dry season lasts from about May to October and rains begin in November and reach their height around January and February. Elevations are <50 m above sea level. Using the land cover map developed by Laumonier et al. (2010), forests comprised 23% of the land cover within a 10-km radius of the SECC, with the remainder classified as non-forested. These forests are regenerating following selective logging operations in the late 1980s. Extensive palm oil plantations, small-scale agricultural areas and human settlements comprised the majority of non-forested lands. In addition to 23 elephants captured as part of the government’s human-elephant conflict mitigation program

Figure 2. Wild single herd of elephant.

and housed at the SECC, a population of about 40-60 wild elephants, most of which seem to range as a single herd, inhabits the SECC. With extensive agriculture and human settlements surrounding much of the SECC, there is much human-elephant conflict in the area.

MATERIALS AND METHODS

From the single herd of elephants, we captured, for the purposes of this study, one adult (~25 years old) wild female from elephant back (Figure 2), (Sitompul, 2011), fitted her with a GPS collar (Africa Wildlife Tracking, Inc, Pretoria, South Africa) and observed her until fully recovered from anesthesia. The collar was set to download a GPS fix every eight hours (0100, 0900, 1700 h) from 24 August 2007 to 14 May 2008.

We estimated total and monthly home range sizes using a 100% minimum convex polygon (MCP) (Mohr, 1947) and a 95% fixed kernel (FK) method (Powell, 2000). Despite its limitations (Powell, 2000; Osborn, 2004), we used the 100% MCP estimate to facilitate comparisons with other elephant telemetry studies. We calculated all home range sizes using the Hawths Tool extension in ArcGIS 9.2 (http://www.esri.com/software/arcgis). We allowed the program to automatically select the appropriate smoothing parameters (href estimate or least-squares cross validation). We used a Spearman correlation test to assess the relationship between monthly elephant home range size and rainfall.

As an index of daily movement, we measured the linear distance between locations on consecutive days. We calculated total monthly movement based on the summation of these daily movements, and used a Spearman correlation test to investigate the relationship between monthly elephant movement and rainfall.

We used a univariate correlogram (Legendre and Legendre, 1998), plotting distance classes between point locations (Cliff and Ord, 1981), and Moran's I autocorrelation coefficient (Moran, 1950) to assess the level of autocorrelation among elephant locations. We used GeoDa^{TM} spatial autocorrelation analysis software (Anselin, 2003) for all autocorrelation analyses. There was autocorrelation between elephant locations ($n = 350$, $I = 0.1268$, $p < 0.001$), but little autocorrelation when we re-sampled the data to include only the 99 locations separated by 48 h ($I = 0.06$, $p < 0.07$), and we used these re-sampled locations for the logistic regression analyses.

We used the Information Theoretic Approach (Burnham and Anderson, 2002) to examine the effects of vegetation productivity and distance to roads and rivers on elephant movements related to habitat use. We generated 99 random points as 'non-elephant' location within the elephant home range. We used these non-elephant locations (0) in combination with uncorrelated observed elephant locations (1) to create a binomial dataset for a logistic regression model. The Enhanced Vegetation Index (EVI), an index of canopy photosynthetic capacity (Gao et al., 2000; Huete et al., 2002, 2006) and possibly primary productivity (Sims et al., 2006), was obtained from the NASA Moderate Resolution Imaging Spectro-radiometer (MODIS) sensor. The spatial resolution of EVI MODIS was 500 m with time series of 16 days obtained from the U.S, Geological Survey (http://glovis.usgs.gov). We determined distance to roads (ROAD) and rivers/streams (RIVER) by measuring the closest distance of elephant locations to these two features. All roads in the study area were abandoned logging roads no longer used by vehicles.

For the regression analyses, we developed seven combinations of models to determine what variables best explained elephant movements. We used the 95% confidence interval to assess the effect of each variable in the model. An Akaike Information

Table 1. Model-averaged estimate, unconditional standard errors and confidence interval of effect on elephant movement in Seblat Elephant Conservation Center.

Parameter[a]	$\hat{\beta}_j$	*SE*	95% CI	
			Upper	Lower
Intercept	0.9435	1.0311	2.9644	-1.0775
EVI	-2.4781	1.7923	1.0348	-5.9910
RVR	-0.0003	0.0006	0.0008	-0.0014
ROAD	-3.51e-05	0.0003	0.0006	-0.0006

[a]EVI, Enhanced vegetation index, RVR, distance to the nearest river, ROAD, distance to the nearest ex-logging road.

Table 2. Summary logistic regression models of elephant locations with vegetation productivity (EVI), and distances to river (RVR) and roads (n=198). Models are ranked from best to worst based using Akaike's Information Criterion (*AIC*) , and associated delta (*Δ AIC*), Akaike weight (*ω*).

Model	*K*	*AIC*	*Δ AIC*	ω_i
EVI	2	276.52	0.00	0.3399
RVR	2	278.14	1.62	0.1512
EVI + RVR	3	278.23	1.71	0.1446
ROAD	2	278.48	1.96	0.1276
EVI + ROAD	3	278.50	1.98	0.1263
RVR + ROAD	3	280.12	3.60	0.0562
EVI + RVR + ROAD	4	280.19	3.67	0.0543

Criteria (AIC) value was calculated for each model, and associated delta (*Δ AIC*), and Akaike weight (*ω*) (Burnham and Anderson, 2002). We also calculated model-averaged parameter estimates, and unconditional standard errors for each parameter (Burnham and Anderson, 2002). We used R- open source statistical software (http://cran.r-project.org/) for all statistical analysis. Summed data are shown as mean ± standard error of mean (SD).

RESULTS

We recorded 358 locations for the GPS-collared adult female elephant between August 2007 and May 2008. Her home range size was 97.4 km^2 for the MCP and 95.0 km^2 for the 95% fixed kernel (Figure 1). Average monthly home range size between September 2007 and April 2008 was 34.6 km^2 (range = 12.4 - 51.7) for MCP, and 47.2 km^2 (range = 28.7 - 65.2) for the 95% fixed kernel. There was no relation between average monthly elephant home range sizes and rainfall (r_s= 0.19; P = 0.65).

The mean daily movement distance of the elephant was 1.5 ± 0.3 km. Average monthly elephant movement was 36.6 km ± 4.6 km. There was no correlation between monthly elephant movement distances and rainfall (r_s = 0.55; P = 0.16). Over half (57%, *n* = 204) of elephant locations were inside the SECC, and 41% (n = 147) in undeveloped forested areas surrounding the SECC. Only 2% (n = 7) of the locations occurred in palm plantations.

The mean distances of elephant locations to rivers were 286 m ± 210 and 291 m ± 198, respectively for the complete and re-sampled data sets. Mean distances of elephants to roads were 686 m ± 524 and 734 m ± 494, respectively for the complete and re-sampled data sets. The mean EVI value for the complete data set was 0.53 ± 0.09.

Given the data from elephant locations and random point locations, the best approximating model showed that elephant distribution was mostly related to our vegetation index (EVI; Table 1; Burnham and Anderson, 2002) and had the largest effect on elephant distribution in the regression model ($\hat{\beta}_j$ = -2.4871, SE = 1.792), (Table 2). The very small parameter estimates for river and roads suggest these variables may be less important factors affecting the habitat use of this elephant.

DISCUSSION

Although the movements of only one elephant were followed in this study, we believe this elephant represent-ed the movements of most of the wild elephants in the Seblat ECC. On eight occasions, we were contacted by plantation mangers when elephants were crop-raiding palm plantations. On each of these occasions, the single GPS-collared female elephant in the study was in close vicinity of the location where elephants were reportedly crop-raiding. This coincidence of GPS locations with crop-raiding instances suggests that there may be only one breeding elephant herd in Seblat, an observation further supported by rangers who report seeing no more than one breeding herd on their regular patrols throughout the SECC.

The elephant home range size we describe was relatively small compared to ranges reported for Asian elephant studies in India (Sukumar, 1989), but larger than the home ranges of the four bulls tracked in Taman Negara, Malaysia (Olivier, 1978). In contrast, home ranges of African elephants are substantial larger than those reported for Asian elephants (Western and Lindsay, 1984; Conybeare, 1991; Lindeque and Lindeque, 1991; Abe, 1994; Thoules, 1996; Osborn, 1998). The small ranges of the Sumatran and Malaysian elephants compared to Indian and African elephants are probably most affected by the stability of environmental conditions. In dry areas, such as the savanna and deciduous forest elephant habitats of India and Africa, elephants tend to increase their home range sizes seasonally in search of food and water (Sukumar, 1989; Lindeque and Lindeque, 1991; Thouless, 1995; 1996; Leggett, 2006). In contrast, annual rainfall is stable and relatively high (> 3000 mm/year) in Sumatra, providing more consistent water availability, and density and quality of palatable plants for elephants (Sitompul, 2011). Thus, there is less need for elephants in Sumatra to increase their home range size in search of water or food. The absence of a relationship between elephant home range size and rainfall in Sumatra further supports this hypothesis.

Concurrently, high human activity in areas surrounding the SECC may also be restricting elephant home range sizes. Numerous studies report the significant effects of human settlements and illegal hunting on elephant movement patterns (Barnes et al., 1991; Ruggiero, 1992; Tchamba et al., 1995; Sitati et al., 2003). The extensive palm oil plantations, land clearing for human settlements, and illegal logging around the SECC over the past 30 years pose significant barriers to elephant movements. The near absence of elephant locations in palm plantations and human settlements strongly suggest the avoidance of these areas. With few exceptions, all elephant locations occurred within the SECC or the forested areas surrounding the SECC. Despite the occurrence of forests extending to the east and north of the SECC (Figure 1), no elephant locations were recorded. Further, no elephant sign was observed in this forested area on surveys conducted by the Bengkulu Natural Resource Agency in 2007/2008 (Aswin Bangun, *pers. comm*). The settlement of about 200 families on the eastern border of the SECC probably blocks elephants from entering this forested area from the SECC. Further, 53% of the forest cover of the northwestern region of Bengkulu Province (including the SECC) was lost from 1985 to 2007 (Laumonier et al., 2010), fragmenting elephant distribution into relatively small isolated populations. Thus, it is difficult for elephants to move between these isolated forest fragments.

Variation in vegetation photosynthetic capacity and perhaps primary productivity, as measured by the EVI, was the factor most affecting elephant movements on the SECC. The value of the EVI parameter in the model ($\hat{\beta}_j$ = -2.4871) suggests that the GPS-collared elephant was sensitive to canopy structural variations, including leaf area index (LAI), canopy type, plant physiognomy, and canopy architecture (Gao et al., 2000), and that cover types with lower gross productivity (example, forests with intermediate canopy cover versus closed canopy forests).

Distances to rivers and roads did not appear to affect the elephant's movements in the SECC. This result contrasts greatly with African elephant movements that are greatly affected by water availability (Redfern et al., 2003; Leggett, 2006; Chamille-Jammes et al., 2007; Lee and Graham, 2006; Cushman et al., 2010), especially in semi- and arid environments. Similarly, Cushman et al., (2010) reported that elephants avoided roads in their satellite telemetry study in southern Africa. The high availability of water in the Seblat and Air Rami rivers, abundance of tributary streams, high rainfall and small area of the SECC combined with the small home range of the monitored elephant suggest that she was never far from a water source. Similarly, distance to the abandoned logging roads also did not appear to affect the elephant's habitat use in the SECC; however, she regularly occurred near roads. African elephants often use traditional elephant trails to move between important resources (Blake et al., 2008). Yet, the use of roads by elephants in SECC may also increase their risk to poachers. There were at least four elephants killed by poachers on the SECC between 2007-2009.

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