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Original Investigation

A landscape-level assessment of Asian elephant habitat, its population and elephant–human conflict in the Anamalai hill ranges of southern Western Ghats, India

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ABSTRACT

Spatial information at the landscape scale is extremely important for conservation planning, especially in the case of long-ranging vertebrates. The biodiversity-rich Anamalai hill ranges in the Western Ghats of southern India hold a viable population for the long-term conservation of the Asian elephant. Through rapid but extensive field surveys we mapped elephant habitat, corridors, vegetation and land-use patterns, estimated the elephant population density and structure, and assessed elephant–human conflict across this landscape. GIS and remote sensing analyses indicate that elephants are distributed among three blocks over a total area of about 4600 km². Approximately 92% remains contiguous because of four corridors; however, under 4000 km² of this area may be effectively used by elephants. Nine landscape elements were identified, including five natural vegetation types, of which tropical moist deciduous forest is dominant. Population density assessed through the dung count method using line transects covering 275 km of walk across the effective elephant habitat of the landscape yielded a mean density of 1.1 (95% CI=0.99–1.2) elephant/km². Population structure from direct sighting of elephants showed that adult male elephants constitute just 2.9% and adult females 42.3% of the population with the rest being sub-adults (27.4%), juveniles (16%) and calves (11.4%). Sex ratios show an increasing skew toward females from juvenile (1:1.8) to sub-adult (1:2.4) and adult (1:14.7) indicating higher mortality of sub-adult and adult males that is most likely due to historical poaching for ivory. A rapid questionnaire survey and secondary data on elephant–human conflict from forest department records reveals that villages in and around the forest divisions on the eastern side of landscape experience higher levels of elephant–human conflict than those on the western side; this seems to relate to a greater degree of habitat fragmentation and percentage farmers cultivating annual crops in the east. We provide several recommendations that could help maintain population viability and reduce elephant–human conflict of the Anamalai elephant landscape.

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Introduction

India holds about 60% of the global population of the Asian elephant (*Elephas maximus*) in the wild (Sukumar 2003; Riddle et al. 2010) and three of the 34 global “biodiversity hotspots” (Myers et al. 2000; Mittermeier et al. 2005), with diverse vegetation types and significant number of endemic fauna and flora (Gadgil and Meher-Homji 2003). In recent decades, the country has enacted

several laws to establish National Parks and Wildlife Sanctuaries (Protected Areas – hereinafter referred as PAs) as well as to conserve the forest cover and protect its wildlife (Bist 2002). Nevertheless, such a PA network in itself is still inadequate to conserve a wide-ranging species such as the elephant. Elephants have large home ranges that extend across PAs and other land-use categories including privately owned lands (Desai 1991; Baskaran et al. 1995). Asian elephants still occur in isolated populations across much of their historical ranges, and many of these are still threatened by habitat loss and degradation, poaching for ivory and other products, and direct conflict with humans especially in cultivated land (Sukumar 1989; Riddle et al. 2010). The species is currently listed as ‘endangered’ (IUCN Red List 2010), included

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in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES: UNEP-WCMC 2003), and in Schedule I of India's Wildlife Protection Act (1972).

The Indian government launched 'Project Elephant' in 1992 to initiate comprehensive measures for elephant conservation in the wild and in captivity (*Project Elephant: Gajatme* 1993). Under this scheme, traditionally important elephant habitats have been designated as Elephant Ranges across the country with most of them spread across more than one state. Elephant Range areas falling under each state have been notified as Elephant Reserves (Bist 2002). There are presently 11 Elephant Ranges and 25 Elephant Reserves in 12 states, spread across 58,000 km², harboring more than 20,000 elephants or about two-thirds of the wild elephant population of the country (*Project Elephant* 2004). More recently, the government carried out a review of Project Elephant through a task force that suggested several measures to correct ongoing efforts with a view to strengthening the conservation of the species (Rangarajan et al. 2010). The need for maintaining the overall integrity of an entire landscape of the population-level distribution of a species has been recognized as the key management option for the long-term conservation of the species. Nevertheless, detailed spatial data at the landscape scale needed for formulating land-use policy for conservation of the species are still lacking in most Elephant Ranges.

Project Elephant Range 9 (5700 km²), geographically known as the Anamalai (meaning 'elephant hill'), Nelliampathy and Palani hill ranges (henceforth "Anamalai Landscape") is located to the south of the Palghat Gap in the southern Western Ghats. This area, believed to harbor about 2000 elephants (Sukumar et al. 1998; Bist 2002), has been identified as one of the potential landscapes for the long-term conservation of the species (Santiapillai and Jackson 1990; Leimgruber et al. 2003; Sukumar and Santiapillai 2006). This population is genetically more diverse and distinct from the much larger elephant population further north in the Ghats (Vidya et al. 2005). This region is also known for its rich biodiversity (Subramanyam and Nayar 1974; Kannan 1998; Umapathy and Kumar 2000; Gadgil and Meher-Homji 2003; Kumar et al. 2004a). On the other hand, the landscape has witnessed a variety of developmental activities such as commercial tea (*Camellia sinensis*), coffee (*Coffea arabica*) and cardamom (*Elettaria cardamomum*) plantations, several hydroelectric and irrigation projects with cut-open canals, and other forms of infrastructural development that impede the movement of elephants (Sukumar 1989; Easa et al. 1990; Kumar et al. 2010). As elephants are known to generally show high fidelity to their home ranges and the corridors that they have traditionally used on a seasonal basis (Baskaran et al. 1995), such land transformations may be the cause of increased elephant–human conflicts in some parts of their range as in the Valparai plateau (Kumar et al. 2004b, 2010).

Despite the threats facing the long-term survival of elephants in this landscape that has high potential for long-term conservation, information on the status of elephant habitats and its vegetation and land-use patterns is scant. Further, robust estimates of population density and demography, which were unavailable for the Anamalai Landscape, are important for the planning of long-term conservation of species (Sukumar 1989). We therefore conducted an extensive field survey during 2005–06 across the Anamalai landscape with the broad objectives of (1) map elephant habitat including corridors, vegetation and land-use patterns, (2) estimate elephant density across the landscape and determining population structure, and (3) evaluate elephant–human conflict in order to provide a more objective basis for deciding upon regional conservation action.

Material and methods

Study area

The Western Ghats run in a north-south direction over 1600 km parallel to the west coast of peninsular India. The Anamalai hill ranges (comprising Anamalai, Nelliampathy and Palani hills) are situated in the southern Western Ghats (76.38° E and 10.44° N to 77.55° E and 10.34° N) to the south of the Palghat Gap, extending over an area of c. 5700 km². The landscape is characterized by its wide altitudinal gradient ranging from c. 100 m above MSL on either side of the Ghats to 2694 m at Anaimudi Peak, the highest point south of the Himalaya. The sharp altitudinal gradient results in significant variation in the amount of precipitation across the landscape, with the western face and crest-line of the hills enjoying higher rainfall (mean annual rainfall up to 3500 mm), and the eastern rain shadow region receiving lower annual rainfall (mean rainfall about 800 mm). The rainfall gradient from east to west, along with the complex topography, results in heterogeneous vegetation types: from lowland tropical dry thorn forest mostly on the eastern side, mid-elevation tropical dry and moist deciduous forests, high elevation tropical semi-evergreen and evergreen forests to stunted montane forests (locally known as *sholas*) and grasslands (Subramanyam and Nayar 1974). This heterogeneous landscape supports diverse faunal communities, including several endemic and endangered fauna, and notable endemics including limbless amphibians (caecilians), burrowing snakes (uropeltids), and mammals such as lion-tailed macaque (*Macaca silenus*), Malabar civet (*Viverra megaspila*), Nilgiri tahr (*Hemitragus hylocrius*) and Nilgiri langur (*Semnopithecus johnii*) (Nameer et al. 2001; Gadgil and Meher-Homji 2003; Kumar et al. 2004a). Agricultural land use patterns vary across this landscape depending on the extent and seasonality of rainfall; thus, the moister and more western part of the landscape supports perennial crops such as coffee *Coffea arabica*, pepper *Capsicum annuum*, cardamom *Elettaria cardamomum*, rubber *Hevea brasiliensis*, banana *Musa acuminata* and coconut *Cocos nucifera*, while the drier eastern part of the landscape with flat plains features annual crops such as paddy *Oryza sativa*, maize *Zea mays*, finger millet *Eleusine coracana* to a greater extent.

Mapping of elephant habitats and corridors

To identify and map "elephant habitat" and "elephant corridors", all "forest divisions" in the landscape were sequentially surveyed. We first define the various terms used in this paper. A "forest division" is a legal notification whose area comprises lands (typically forests or grasslands) administered by the forest department, as well as government land leased for other purposes such as plantations; the area of a forest division we report here is determined from official records and GIS analysis of maps. Elephant habitat is further split into two categories – "elephant distribution area" refers to contiguous natural habitat within the overall boundaries of forest divisions that show elephant presence but may include rarely used or inaccessible rocky and steep terrain, while "effective elephant habitat" would exclude such inaccessible land within the contiguous matrix. We have not determined effective elephant habitat for individual forest divisions, a task that would require a much finer resolution survey and sampling in a landscape of complex topography (though we make a crude estimate for the landscape based on the literature). Elephants may also range in natural habitat outside the forest divisions but these areas (usually small) are not factored into our estimations. An "elephant corridor" is defined as a relatively narrow strip of habitat that provides a passage for elephants to move between two larger expanses of habitats; a corridor is thus a bottleneck for elephant movement over the larger landscape (Sukumar 2003; Venkataraman 2005). During

the survey in each forest division, boundaries of forest division and ranges were marked on topographic maps of 1:50,000 scale at the forest division office in consultation with the concerned officials and by referring to documents such as forest working plans and topographic maps maintained in the division. To identify elephant distribution area, we consulted with officials to arrive at a coarse-level map and subsequently fine-tuned this through field surveys with a GPS (Global Positioning System) using direct observation of elephants, or their indirect evidences such as trails and footprints, dung, and feeding signs. Similarly, to identify elephant corridors, we first examined natural habitat contiguity and topographic features on maps, discussed elephant movement with officials, and subsequently confirmed this in the field using direct sightings or indirect signs of elephant.

Forest division and range boundaries marked on topographic maps were digitized using Geographical Information System (GIS) software (Arc View 3.3, ESRI Inc.), and information on elephant habitats and corridors incorporated. In addition, layers such as major rivers, highways, contour lines, and settlements and cultivation obtained from the topographic maps were overlaid. Elevation contours were extracted from Shuttle Radar Topography Mission (SRTM) database taken in 2001 from the Global Land Cover Facility (GLCF) website. Global Mapper v 4.78 was used to generate elevation contours from SRTM data at intervals of 100 m. Contours were then extracted as shape files, those from all degree tiles merged, and sub-setted for the study area in Arc View. Arc View extension 3D Analyst was used for all 3D analysis functions. Triangular Irregular Network (TIN) surface was created from the contours. Slope of the terrain was then derived from this TIN surface. Finally the image mosaic was overlaid on the TIN surface to have a 3D view of the terrain topography especially to illustrate the corridor areas. Incorporating these details, we created a GIS-based database on elephant habitats of the Anamalai landscape and extracted the extent of forest and non-forest areas, elephant distribution area, and elephant corridors present under each forest division.

Mapping of vegetation and land-use patterns

Mapping of vegetation and land-use patterns was carried out through supervised classification of satellite imagery using ground-truth data. During the field surveys, different landscape elements (LSE) were identified using differences in land-use pattern and vegetation composition. The earlier classification of the French Institute (Pascal et al. 1982) was used as the basis for this exercise. From each LSEs, ground truthing was carried out at multiple locations by laying 20 m × 20 m plots (ground truth plots) for natural forest areas to determine tree species composition and vegetation type, and without laying any plot for a given point (ground-truth points) for non-forest elements (like settlement and cultivation) and monoculture forest plantations. From all the ground-truthing plots and points, details of variables such as latitude and longitude (using GPS) were recorded. The ground truth data on LSE were then used as reference for generating a land-use map from satellite imagery. Satellite images from multispectral scanner LISS IV (with spatial resolution of 23.5 m obtained in January–February 2004) on board IRS 1D were used for vegetation and land-use patterns mapping. Image processing was carried out in ERDAS Imagine 8.3.1 by the following steps:

(1) Preliminary processing of satellite images: Satellite images of the Anamalai hill ranges were selected and unclear portions enhanced through either sharpening or smoothing (Jensen 2007). The images were geo-referenced using control points, obtained from topographic sheets and field surveys and re-sampled using nearest neighborhood algorithm (Lillesand and

Kiefer 2000). After geo-registration, all images of the study area were mosaiced into a single image.

- (2) Supervised classification: A total of 102 training sites were created for various landscape elements using information from 204 ground truthing plots and 517 ground truthing points collected during field survey. In addition, the vegetation maps from French Institute (Pascal et al. 1982) were referenced for certain areas. Based on signatures files created from these training sites, the remaining image pixels were classified using Maximum Likelihood Classifier algorithm (Lillesand and Kiefer 2000). This classification delineated different LSEs for the entire range. Their areas were then calculated separately for each forest division.
- (3) Accuracy assessment: A set of 603 ground truth points collected across the landscape was used as reference points for assessing the accuracy of the classification using standard method. The overall accuracy was computed by dividing the total number of correctly classified pixels by the total number of reference pixels (Lillesand and Kiefer 2000). The average overall accuracy for the land cover classification of landscape was 77.9% (\pm SD = 18.69, $n = 19$) while the average kappa statistics was 0.735 (\pm SD = 0.207, $n = 19$) that seems to be a satisfactory outcome for our purposes (Congalton and Green 1999).

Elephant density estimation

In view of the dense tropical forest vegetation of this region that makes direct observation of elephants difficult, we used the line transect, indirect – dung count – method (Barnes and Jensen 1987; Dawson and Dekker 1992). This method estimates the density of dung piles in a given area using the line transect method (Burnham and Anderson 2002) and converts the dung density into elephant density using defecation and dung decay rates with the following function.

$$E = \frac{Y \times r}{D}$$

where E is the density of elephants, Y is the density of dung, r is the daily rate of decomposition and D is the number of dung piles deposited per elephant per day.

For estimating dung density, topographic maps of the study area (1:50,000 scale) were overlaid with 25 km² (5 km × 5 km) grids, and the 280 resulting grids serially numbered. Selecting the odd numbered grids for sampling, we randomly placed one transect (of 1–2 km length; the length of the transect depended on topography and logistics) within each grid, taking care to lay the transect across the altitudinal gradient. In total, 140 transects covering 275.4 km across all forest divisions and vegetation types of elephant habitats in the landscape were surveyed once. Of the 140 transects, 75 (110.7 km) were surveyed during February–April 2005 and the rest during February–April 2006. All dung piles seen from the transect line were recorded and, for each dung pile, the perpendicular distance from the transect line to the center of the dung pile was measured to the nearest cm using a measuring tape. From the dung count data, we estimated dung density using distance-sampling techniques (Program DISTANCE version 6.0; Buckland et al. 2003; Thomas et al. 2005) for maximum detection distances of 12 m, 14 m and 16 m depending on sample size and outliers in each set of data. We evaluated different models of detection probability (half-normal, uniform and hazard rate) with cosine adjustment; the best-fit model for each dataset was assessed using Akaike's Information Criterion (AIC) value. The analyses were carried out either separately for each forest division or by pooling the data of adjoining divisions with similar elephant dung density to fulfill a minimum sample size

requirement of 40 dung piles. Similarly, dung density for the landscape was estimated using pooled data from all the forest divisions.

We used the method of estimating dung decay rate that was in vogue at the time of our study (Barnes and Jensen 1987; Dawson 1990; Dawson and Dekker 1992) before a newer method of marking dung and statistical analyses was adopted by the CITES/MIKE programme as the favored method (Hedges and Lawson 2006) based on Laing et al. (2003). To estimate the daily rate of dung decay, 1298 fresh dung piles representing various habitats were marked at weekly intervals between December 2004 and March 2005 (beginning about two months prior to the first line transect survey for dung density) and monitored by us and field staff of Tamil Nadu Forest Department up to June 2005 until all the dung piles decayed completely (i.e. disappeared). Daily dung decay rate, computed as the reciprocal of the time for dung piles to decay completely, obtained from this sample was 0.011 ± 0.000018 (SE); with 95% confidence intervals of 0.0104 and 0.0116. We used the elephant daily defecation rate of 16.33 ± 0.003 (SE) estimated at Mudumalai Wildlife Sanctuary in southern India (Watve 1992), a region with similar vegetation and climate (in any case, the defecation rate is similar elsewhere as, for instance, in northeastern India: 16.16 ± 0.37 (SE), Baskaran et al. 2004).

Given several statistical problems in estimating on the variance of mean elephant density, we used Monte Carlo methods (Barnes 1993; Santosh and Sukumar 1995) to arrive at mean and 95% confidence limits of elephant density by incorporating the three variables (dung density, daily defecation rate, and daily dung decay rate) and their variances into the simulation Program GAJAH 1.1 (Archana and Sukumar unpublished). Elephant density estimates have to be cautiously extrapolated to potential elephant habitat area for obtaining elephant population numbers as part of the area would be inaccessible and unused by elephants.

Elephant population structure

Data on age–sex were collected whenever an elephant herd or bull was sighted during our systematic field surveys in different forest divisions. Our assumption here is that solitary adult bulls and female-led family groups had equal probability of being sighted; while larger groups such as elephant families could have a higher probability of being detected, the much larger body size of adult bulls and their tendency to be less shy of people could compensate for any bias in detection. For every sighting, information such as date and place of sighting, group size and age–sex composition were recorded. Characteristic features of individual elephants (if any) were also recorded in order to differentiate individual herds and bulls (Arivazhagan and Sukumar 2008). Age estimation was done based on shoulder height described by Sukumar et al. (1988). All elephants that were sighted were classified into calf (<1 year old; 90–120 cm), juvenile (1–2, 2–3, 3–5 years old; 120–180 cm), sub-adult (5–10, 10–15 years old; 180–210 cm for female and 180–240 cm for male) and adult (15–20, 20–30, 30–40, 40–50 and >50 years old; above 210 cm for female and above 240 cm for male). Sex differentiation was not possible for elephants below 2 years and thus assumed equal, as studies on captive elephants have shown that the sex ratio at birth does not deviate significantly from equality (Sukumar et al. 1997; Mar 2007). Due to very low frequency of adult bulls in the population, we first used all elephant sightings ($n = 139$ elephants) to determine the proportion of this category, and a subset of sightings ($n = 89$) in which all elephants were clearly classified for age/sex to determine age structure of the population.

Elephant–human conflict assessment

A rapid questionnaire survey was carried out during January–February 2006 sampling 176 villages (covering 50% of the total villages and farmers, representing both periphery and enclave) located within and around the 19 forest divisions, to assess the intensity of elephant–human conflict. At each village, farmers were interviewed for basic information on extent of cultivated land and location, type of crops cultivated, and elephant damage to crop and properties for the year 2005 [see Annexure 1]. Human deaths due to elephants and elephant mortality/capture as a result of conflict were also noted. Secondary data on compensatory (*ex gratia*) payments toward crop and property damage, and human deaths, were collected for the period from April 2000 to March 2006 for various forest divisions from official records. Differences in number of farmers and villages affected by elephants as well as the extent of annual crops cultivated between the eastern and western part of the landscape were tested using a chi-square test. Further, the relationship between the extent of elephant–human conflict with various habitat attributes was explored using multiple regression. In the multiple regression framework, the dependent variable was the extent of conflict (percentage of farmers affected by elephants) in each division while the independent variables were the perimeter of the forest division, two simple metrics of habitat fragmentation (ratio of perimeter of non-forest elements to area of elephant habitat; number of forest patches within each division), moisture levels (proportion of evergreen forest), elephant density, and type of crops cultivated (percentage of farmer cultivating annual crops). At first the relationship between the dependent variable and independent variables were tested using scatter plots. Based on the relationship of independent variables, the variable was entered either in linear form or non-linear form with quadratic term. When the relationship was quadratic, both independent variable and its square term were entered into the multiple regression model. If the quadratic term turned out to be insignificant, it was dropped. At the end, only significant independent variables were retained in the equation.

Results

Status of elephant habitat, vegetation and land-use patterns

The Anamalai landscape comprises 19 forest divisions spread over 5823 km² (Table 1); however, only 4588 km² falls within the elephant distribution area. A major part of the elephant distribution area in the landscape remains contiguous while the remaining area is divided into two patches (one comprising a part of Idukki Wildlife Sanctuary and Kothamangalam Forest Division, and the second a part of Theni Forest Division), due to topographical constraints of steep contours and land use (settlement/cultivation) (Fig. 1). Settlements as well as the steep terrain between the southwestern part of Munnar Forest Division and the northeastern part of the Kothamangalam Forest Division seem to act as barriers to elephant movement in spite of forest contiguity between these two areas. Munnar Forest Division and the Theni Forest Division are presently separated by plantations of tea and cardamom, though elephants continue to move through some of these plantations.

Human settlements and cultivated lands cover 403 km² while commercial plantations of tea, coffee, cardamom and rubber occupy 851 km² within the landscape under various forest divisions (Table 1). A division-wise estimate of non-forest attributes (settlement/cultivation and commercial plantations) shows that forest divisions such as Munnar followed by Indira Gandhi Wildlife Sanctuary (IGWLS), Theni and Marayur on the eastern side of

Table 1
Extent of total area, extent of elephant habitat (natural forest, grassland and forest plantation) as seen from actual distribution, and non-forest area (in terms of settlements, cultivation and commercial plantations of tea, coffee and cardamom) available under various Forest Divisions in the Anamalai landscape using GIS analysis. Please note that elephants may sometimes move through the non-forest areas. In some divisions the area under settlements/cultivation and commercial plantations have been recorded as part of the forest division area [e.g. Munnar] especially if these are leased for non-forest land use, while in others [e.g. IGWLS] such land use is excluded, especially if these are private lands.

Forest division (State)	Area (km ²)		Extent of non-forest elements in km ² (number)		Forest division perimeter (km)	No. of forest patches
	Total	Elephant habitat	Settlements/cultivation	Commercial plantations ^a		
Chinnar WLS (KL)	94.7	92.9	1.7 (5)	0(0)	56	1
Dindugul (TN)	182.9	172.9	0.9 (1)	9.09 (1)	220	2
Eravikulam NP (KL)	119.8	119.7	0(0)	0(0)	104	1
IGWLS (TN)	958.3	956.7	1.6 (2)	166.5 (2)	447	1
Kodaikanal ^b (TN)	82.3	82.3	0(0)	16.7 (7)	88	1
Marayur (KL)	193.8	159.2	34.6 (9)	3.5 (1)	83.5	4
Munnar (KL)	1206.5	667.9	159.5 (60)	379 (73)	347	44
Theni ^c (TN)	279.2	235.6	3.2 (3)	40.2 (35)	246	1
Eastern side of landscape	3284	2487.2	201.5 (80)	615.0 (119)	1592	55
Chalakudy (KL)	229.9	164.5	17.6 (9)	47.7 (3)	127	6
Chimmony WLS (KL)	95.2	95.2	0(0)	0(0)	57.2	1
Idukki WLS (KL)	128.0	125.4	2.3 (5)	0.3 (1)	137	1
Kothamangalam (KL)	165.9	33.2	82.1 (8)	50.5 (2)	120	3
Malayattur (KL)	637.4	600.6	12 (9)	24.6 (14)	159	5
Mankulam Wild Life (KL)	91.3	85.9	5.3 (7)	0.07 (1)	78.4	1
Nemmara (KL)	373.2	217.1	76.7 (1)	79.4 (21)	139	2
Parambikulam WLS (KL)	288.2	283.9	0.003 (1)	4.2 (3)	112	3
Peechi WLS (KL)	106.6	103.9	0.5 (4)	2.0 (1)	72	1
Thattakad Sanctuary (KL)	29.7	24.6	2.7 (3)	2.3 (1)	26.1	2
Vazhachal (KL)	393.8	366.2	2.4 (3)	25 (4)	169	5
Western side of landscape	2539.2	2100.5	201.60 (50)	236.07 (51)	1197	30
Landscape	5823.2	4587.7	403.10 (180)	851.06 (170)	2799	85

^a Includes plantations of tea, coffee, rubber and cardamom. KL refers to Kerala state and TN to Tamil Nadu state.

^b Only Berijam Range in the division falls within the elephant habitat.

^c Only a part of Theni forest Division falls within the Anamalai landscape.

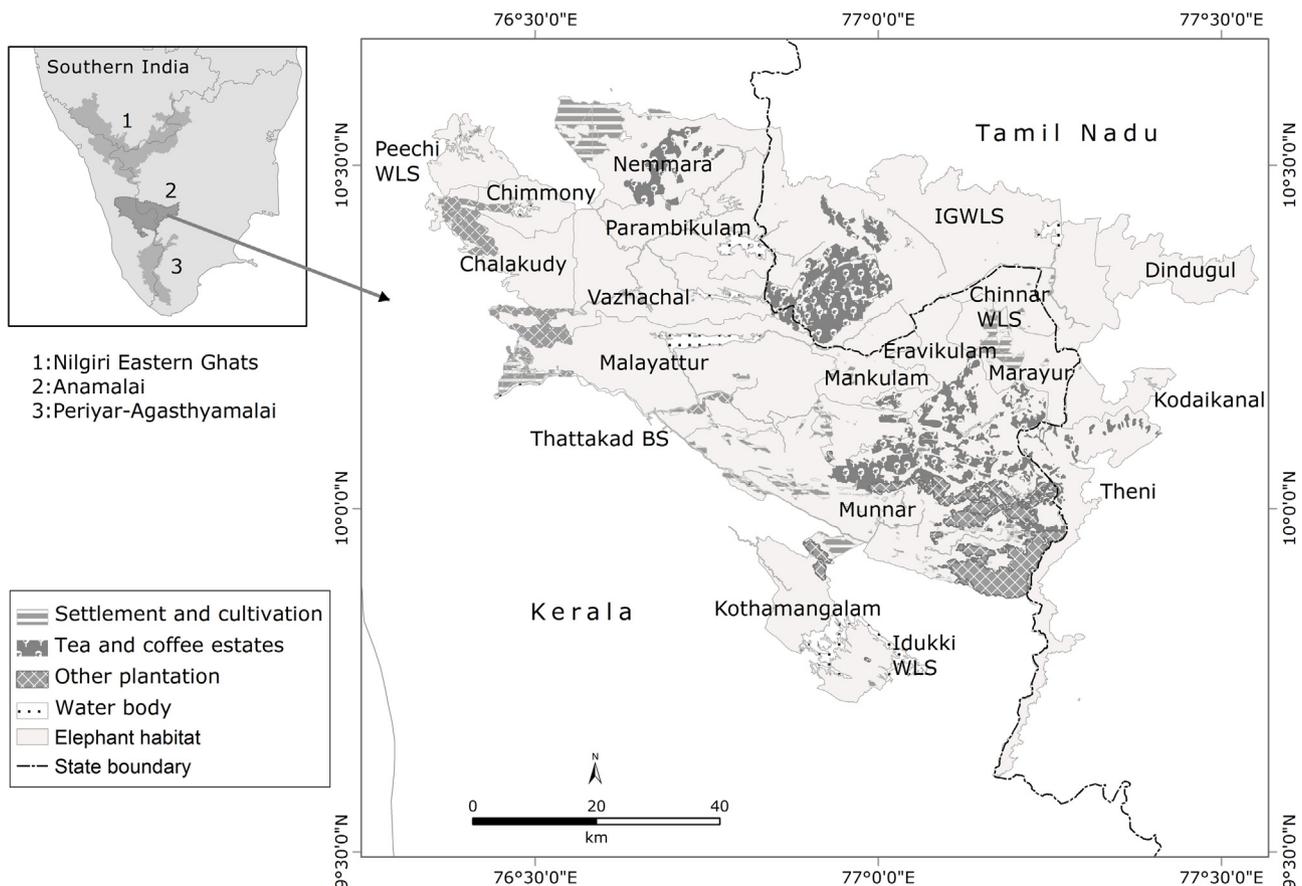


Fig. 1. Map showing various forest divisions, and forest and non-forest elements within the range of elephant distribution in the Anamalai Landscape using GIS analysis.

Table 2

Extent of various landscape elements within the elephant habitats of Anamalai landscape obtained from supervised classification of satellite imagery using ground truth data (see text and legend to Fig. 2 for more details).

Forest division	Forest element (km ²)						Non-forest element (km ²)			Total
	GL	EGF	MDF	DDF	DTF	FPL	NFPL	W	Cu/Se	
Chalakydy	20.5	23.3	97.2	9.1	0.0	23.0	53.6	0.3	5.1	232.1
Chimmony	2.9	22.8	49.7	4.0	5.7	4.4	1.7	4.8	0.0	96.0
Chinnar WLS	8.4	11.7	12.0	23.5	35.5	0.8	0.0	0.0	1.8	93.8
Dindugul	19.0	19.2	38.5	63.5	40.1	1.8	0.8	0.0	0.7	183.6
Eravikulam	71.1	31.9	11.1	6.2	0.0	0.2	0.0	0.0	0.0	120.4
Idukki WLS	28.8	10.1	36.9	15.4	0.0	5.6	0.3	30.0	2.4	129.4
IGWLS	73.0	124.0	106.3	359.7	201.9	87.2	165.5	2.6	5.6	1125.8
Kodaikanal	32.3	5.5	1.9	0.1	2.0	42.3	0.0	0.2	0.0	84.3
Kothamangalam	9.8	30.2	52.0	13.6	0.0	17.7	10.2	0.4	33.3	167.1
Malayattur	26.5	93.0	344.9	28.0	0.0	68.6	24.2	25.2	29.5	639.9
Mankulam	3.6	38.7	28.0	8.5	6.0	1.8	0.0	0.0	5.4	92.0
Marayur	20.7	58.6	23.5	18.8	27.4	9.5	0.0	0.0	34.7	193.4
Munnar	63.3	139.9	210.9	63.2	71.8	76.5	405.7	4.2	181.9	1217.4
Nemmara	11.1	46.2	102.8	66.9	0.0	28.9	49.8	4.4	66.2	376.3
Parambikulam	0.0	77.0	47.7	18.2	0.0	130.9	4.8	12.5	0.3	291.3
Peechi	3.0	89.9	2.5	9.7	0.0	0.0	0.0	2.4	0.6	108.1
Thattakad BS	3.8	4.3	4.8	2.1	0.0	8.9	2.5	1.3	2.8	30.5
Theni	21.2	34.0	24.2	49.8	94.7	10.9	35.0	0.0	9.2	279.0
Vazhachal	10.7	231.2	21.5	21.2	0.0	75.1	25.0	8.1	2.6	395.5
Landscape	430	1092	1216	781	485	594	779.1	96	382	5855.8

Note: GL, Grassland; EGF, evergreen forest; MDF, moist deciduous forest; DDF, dry deciduous forest; DTF, dry thorn forest; FPL, forest plantation (teak, eucalyptus, wattle and pine); W, water bodies; NFPL, non-forest plantations (tea, cardamom, coffee and rubber); Cu/Se, Cultivation and Human Settlements.

the landscape, and Nemmara, Kothamangalam, Chalakydy and Malayattur on the western side have greater levels of non-forest attributes within them (Table 1). Overall, the forest divisions on the eastern part of the landscape (Chinnar, Dindugul, Eravikulam, IGWLS, Kodaikanal, Marayur, Munnar and Theni Forest Divisions), with 25% of the total area under settlements/cultivation and non-forest plantations are more fragmented as compared to forest divisions (Chalakydy, Chimmony WLS, Idukki WLS, Kothamangalam, Malayattur, Mankulam, Nemmara, Parambikulam WLS, Peechi WLS, Thattakad sanctuary, Vazhachal) on the west (with 17% of the total area under settlements/cultivation and non-forest plantations). For instance, the elephant distribution area in forest divisions on the eastern side is greater than the corresponding figure of the western side by only 17%, but the former have 100% more settlements/plantations and 83% more forest patches than the latter part of the landscape.

Satellite image classification estimated about 5856 km² area within this overall landscape, only slightly greater than that obtained from GIS analysis of official maps and records (Table 2). Of this, 79% (4598 km²) is effectively under government (forest department) control while the remaining 21% consist of non-forest area, predominantly plantations of tea, coffee, cardamom, and rubber, figures comparable with the extent of area arrived at from topographic maps (vector layer). Although a major part of the land under the control of the forest department comprises natural forest including grassland (87% – 4004 km²), a substantial part is under monoculture forest plantations (13% – 594 km²) of *Tectona grandis* (teak), *Eucalyptus* spp. (eucalypts), *Acacia* spp. (wattle) and *Pinus* spp. (pine) (Fig. 2). Tropical deciduous and dry thorn forests are found to the extent of about 40% in IGWLS and Malayattur Divisions. Similarly, evergreen forests are more extensive in the Vazhachal Division (231 km²), while grasslands are characteristic of higher altitudes (>1800 m above MSL) in IGWLS, Eravikulam and Munnar Divisions. The large area of tea and cardamom plantations in Munnar Forest Division has not only broken the contiguity of forest areas within the division, but also with the adjoining Theni Forest Division.

Elephant corridors

Five corridors have been identified for this landscape of which four lie within IGWLS and one between Munnar and Theni Forest Divisions (Fig. 3). The passages that elephants presently use to move primarily across an east-west axis can be considered under two major sectors. To the north of the Valparai plateau this movement takes place through four forested corridors: (1) Navamalai – Monkey falls along the foothills (mean: 400 m asl), and (2) Attakatti – Upper Aliyar (mean: 1200 m asl), (3) Aiyarpadi – Waterfalls (mean: 1600 m asl) and (4) Siluvaimedu – Kadamparai (mean: 1400 m asl) on the Valparai plateau in IGWLS but bordered by tea plantations. Elephant movement through these corridors is additionally constrained by vehicular traffic on the highway (between Pollachi and Valparai townships) that cuts across these corridors. Elephants also move through tea plantations located along the southern fringe of the Valparai plateau through the Ryan Tea Plantation Division. In the southeastern part of the landscape, forest contiguity from Munnar Division to the Theni Forest Division via the corridor (5) Mattupatti – Mathikettan Shola is presently broken due to tea and cardamom plantations, but some elephants move between these divisions through these commercial plantations. Further south, however, elephant movement from the Anamalai landscape to the Periyar – Agasthyamalai landscape is blocked since the 1950s by large penstock pipes of the Periyar hydro-electric project. These developmental activities (commercial plantations and hydro-electric project) have also rendered unviable the elephant habitats of Mathikettan Shola and the northern part of Theni Forest Division.

Elephant population density and structure

We recorded 3603 dung piles along 274.5 km of transects for an average encounter rate of 13.1 dung piles/km (Table 3). Mean dung density varied by an order of magnitude from 273 piles/km² at Chimmony/Peechi Forest Divisions to 3144 piles/km² in Malayattur Forest Division. The results of the dung count showed a

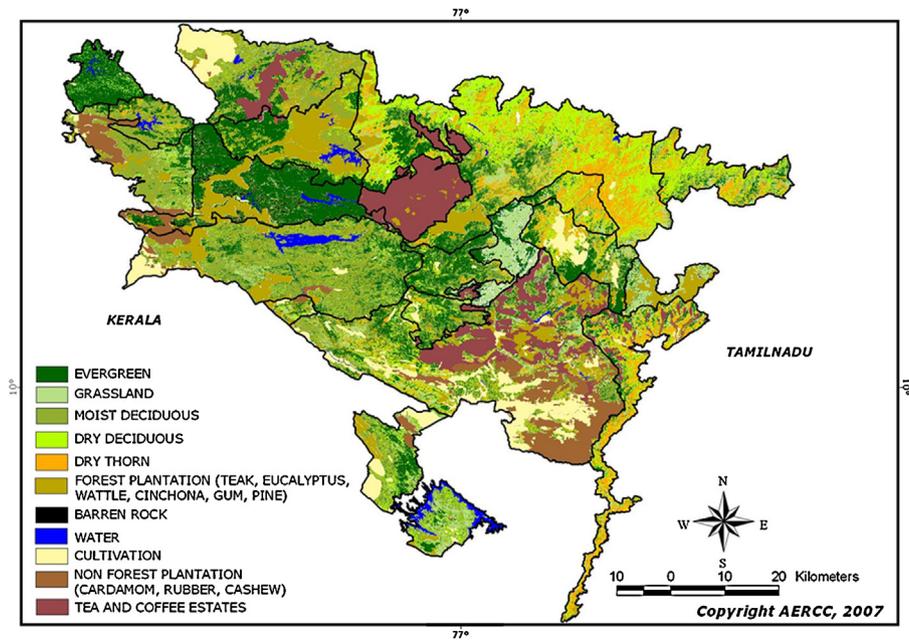


Fig. 2. Vegetation and land use patterns of the Anamalai Landscape obtained from supervised classification of satellite imagery using ground truthing data. Satellite images from multispectral scanner LISS IV (with spatial resolution of 23.5 m obtained in January–February 2004) on board IRS 1D were used for land use/land cover mapping.

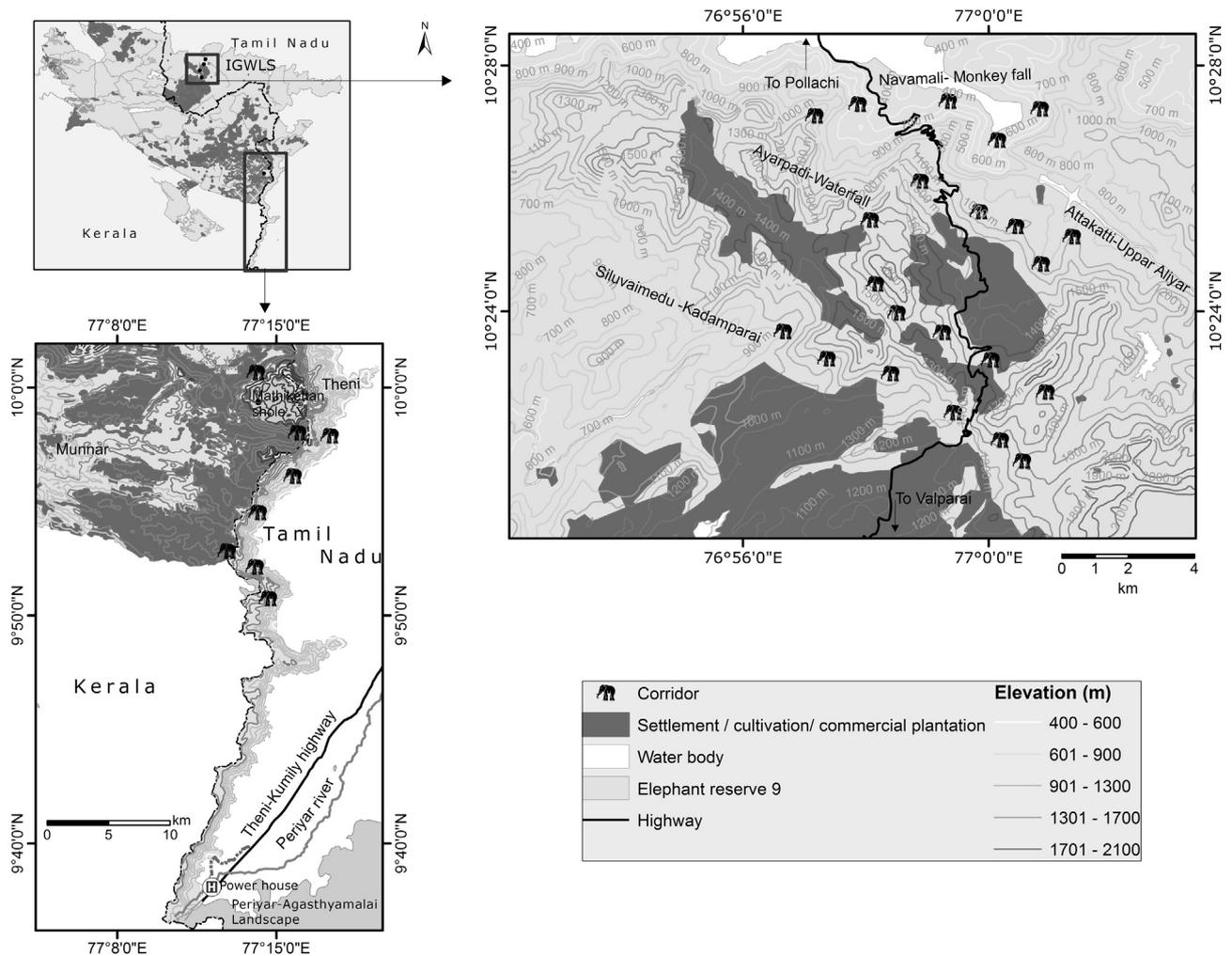


Fig. 3. Map showing the identified corridors and their land use status in relation to topography in the Anamalai Landscape.

Table 3

Density estimate of elephants in various Forest Divisions of the Anamalai landscape obtained using line transect dung count method. LCI and UCI refer to 95% lower and upper Confidence Intervals, respectively. The mean elephant density and confidence limits for the landscape are obtained by pooled analysis of all transects within the landscape.

Forest division	Distance walked – in km (number of dung piles recorded)	Dung density/km ² Mean ± SE	Elephant density/km ² Mean (95% LCI–UCI)
Dindugul	19.0 (310)	1660 ± 131.6	1.1 (0.9–1.3)
IGWLS	57.75 (1789)	2936 ± 108.0	1.9 (1.7–2.2)
Theni and Kodaikanal	33.95 (92)	410 ± 67.9	0.3 (0.2–0.4)
Chalakkudy	16.0 (109)	1382 ± 202.2	0.9 (0.6–1.2)
Chimmony and Peechi	10.0 (31)	273 ± 60.9	0.2 (0.1–0.3)
Chinnar, Eravikulam and Marayur	18.0 (44)	379 ± 65.3	0.3 (0.2–0.4)
Idukki	7.0 (73)	2022 ± 337.6	1.4 (0.9–1.9)
Kothamangalam	8.0 (67)	1332 ± 229.4	0.9 (0.6–1.2)
Malayattur and Thattakad	24.0 (286)	3144 ± 283.8	2.1 (1.7–2.6)
Munnar and Mankulam	31.1 (216)	1270 ± 115.0	0.9 (0.7–1.1)
Nemmara	8.75 (49)	1738 ± 433.2	1.2 (0.6–1.8)
Parambikulam	18.0 (202)	1946 ± 196.6	1.3 (1.0–1.6)
Vazhachal	22.98 (335)	2915 ± 196.0	2.0 (1.7–2.3)
Landscape	274.53 (3603)	1816 ± 45.57	1.1 (0.99–1.2)

mean density of 1.1 elephants/km² for the landscape (95% Confidence Interval: 0.99–1.2 elephants/km²). Forest divisions such as IGWLS, Malayattur and Vazhachal with about 2 elephants/km and Dindugul, Nemmara, Munnar and Parambikulam with about 1.0–1.5 elephant/km² (Table 3) are the important dry season habitats for the elephant population. Although Idukki and contiguous habitats in the Kothamangalam Forest Division support about 1 elephant/km², the approximately 225 elephants of this area are completely isolated from the major population in the Anamalai landscape. The remaining forest divisions in the landscape do not support many elephants during the dry season.

Four adult males were recorded out of 139 elephants sighted; thus, the proportion of adult males is 0.029 or about 3% of the total population. The age structure of 89 classified elephants recorded from 19 sightings showed that the population consisted of 45.2% adults with the remaining 54.8% being sub-adults (27.4%), juveniles (16%) and calves (11.4%). On the other hand, the age/sex structure showed that the proportion of males declined gradually from sub-adult class (>5 years) onwards reaching very low values in the >20 years age class, resulting in a considerable bias toward females in the upper age segments (Table 4). The sex ratio shows a gradual skew toward females from juvenile (1:1.8) to sub-adult (1:2.4) and adult (1:14.7) age classes.

Elephant–human conflict

Overall, in 2005, elephants affected 52% of the 176 villages sampled and 57% of 466 farmers interviewed (Table 5). When only villages in which conflict occurred are considered, 60% of the

Table 4

Age–sex classes of elephants recorded ($n = 89$) between January 2005 and April 2006 in the Anamalai landscape.

Age class	Age segment (years)	% population	
		Female	Male
Calf	<1	5.7	5.7
	1–2	1.1	0
	2–3	5.7	0
Juvenile	3–5	3.4	5.7
	5–7	3.4	1.1
	7–10	5.7	3.4
Sub-adult	10–15	10.3	3.4
	15–20	4.6	1.4
	20–30	11.4	0.7
	30–40	17.1	0
Adult	40–50	8.0	0.7
	>50	1.1	0

farmers in these villages were affected. Regional variations in conflict indicate that the eight forest divisions in the eastern part of the landscape (with 56% of the area) experienced significantly higher conflict levels ($54 \pm 10.3\%$ (SE) farmers in $61 \pm 10.7\%$ (SE) of the 122 villages sampled) as compared to the eleven forest divisions in the western part (44% of the area) ($28 \pm 9.7\%$ (SE) farmers in $23 \pm 8.15\%$ (SE) of the 54 villages sampled) of the landscape (farmers affected: $\chi^2 = 11.32$, $df = 1$, $P < 0.001$; villages affected: $\chi^2 = 22.26$, $df = 1$, $P < 0.001$).

Similarly, the number of human deaths ($n = 5$) and elephant mortality/capture (3) recorded due to conflict in the eastern side was higher as compared to western side (2 human deaths and 1 elephant mortality/capture). Five forest divisions – Kothamangalam, Mankulam, Parambikulam, Peechi and Chimmony – out of 11 divisions in the western part of the landscape did not experience any damage by elephants. All forest divisions in the east experienced conflict, with the exception of Eravikulam and Kodaikanal that had no villages in the elephant distribution areas.

The survey also showed that more farmers cultivated perennial crops (64%) than annual crops (36%) in the landscape. However, the number of farmers cultivating annual (mostly cereals such as paddy, maize and finger millet) and perennial (coffee, pepper, cardamom, rubber, banana and coconut) crops varied significantly between the eastern side and the western side ($\chi^2 = 28.34$, $df = 1$, $P < 0.001$) of the landscape (Table 5) with cultivation in the moister west biased toward perennial crops. Farmers living in the peripheral and enclave villages of forest divisions in the eastern side, especially Dindugul, Theni and Chinnar, cultivated more annual than perennial crops. Further, the multiple regression analysis revealed that among the independent variables tested, perimeter of the forest division and percentage of annual crops cultivated explained 81% of elephant–human conflict incidence (Table 6). While forest perimeter showed a linear relationship with conflict incidence (percent farmers affected), percent farmers cultivating annual crops in a division showed a quadratic trend with conflict incidence, suggesting that conflict initially increases with more farmers cultivating annual crops (perhaps suggestive of increasing area under annual crops) and then declines after a certain threshold (in this instance, about 50% farmers cultivating annual crops).

Discussion

Status of the elephant habitats and corridors

A continental study on the evaluation of Asian elephant habitats (Leimgruber et al. 2003) states that 51% of the geographic range (estimated at <5,00,000 km² by Sukumar 2003) of Asian elephants

Table 5
Elephant–human conflict and cropping patterns recorded in various forest divisions during 2005 through rapid survey (percent villagers and farmers affected by conflict) and *ex gratia* payments by the forest department toward crop/property damage and human injuries/deaths by elephants between 2000 and 2005 in the Anamalai landscape.

Forest division	Rapid survey		<i>Ex gratia</i> (in US \$ mean from 2000–2005)/year		Type of crops cultivated (% farmers)	
	% village affected (number surveyed)	% farmers affected (number surveyed)	Crop and property damage	Human casualty	Annual	Perennial
Chinnar WLS	33.3 (3)	37.5 (8)	0	0	83	17
Dindugul	100 (14)	97.1 (69)	1556	278	63	37
Eravikulam NP	Nil	–	0	0	Nil	Nil
IGWLS	65.9 (44)	72.8 (125)	2323	4081	47	53
Kodaikanal	Nil	–	0	0	Nil	Nil
Marayur	66.7 (12)	45.5 (33)	0	0	37	63
Munnar	72.4 (29)	37.7 (77)	2649	685	4	96
Theni	30.0 (20)	35.5 (62)	487	1667	66	34
Eastern side of landscape	61.4 (122)	54.3 (374)	7014	6711	50	50
Chalakydy	20.0 (5)	20.0 (5)	50	148	0	100
Idukki WLS	50.0 (2)	25.0 (4)	594	0	25	75
Kothamangalam	0 (12)	0 (13)	0	0	0	100
Malayattur	37.5 (8)	63.6 (11)	182	74	28	72
Mankulam Wild Life Div.	0 (2)	0 (2)	0	0	–	–
Nemmara	71.4 (7)	46.2 (13)	682	148	14	86
Parambikulam WLS	0 (3)	0 (3)	0	0	Nil	Nil
Peechi and Chimmomy WLS	0 (4)	0 (4)	0	0	0	100
Thattakad Bird Sanctuary	25.0 (4)	76.9 (13)	0	0	–	–
Vazhachal	28.6 (7)	50.0 (24)	166	296	19	81
Western side of landscape	23.3 (54)	28.2 (92)	1674	666	12	88
Landscape	37.6 (176)	38.0 (466)	8688	7377	36	64

Table 6

Summary output of multiple regression equation model to explore the relationship between elephant–human conflict (percent farmers interviewed who were affected by elephants) in different forest divisions and landscape attributes (perimeter of forest division), elephant density and percent farmers cultivating annual crops.

Set	Variables	Coefficient ± SD	P	Model r^2	Model P
1	Constant	−6.560 ± 7.559	0.404	79.6	0.000
	Perimeter	56.19 ± 14.06	0.002		
	% annual crop	2.1116 ± 0.4294	0.004		
	% annual crop ²	−0.01816 ± 0.007	0.030		
	Elephant density	1.950 ± 5.896	0.747		
2	Constant	−5.310 ± 6.300	0.416	81.1	0.000
	Perimeter	55.95 ± 14.63	0.003		
	% annual crop	2.0053 ± 0.550	0.000		
	% annual crop ²	−0.019570 ± 0.0057	0.005		

consisted of unfragmented wild lands in 1990. Only 10 populations are believed to hold more than about 1000 elephants each across Asia; these include six populations in India of which the Anamalai landscape has been recognized as one such population with prospects for long-term conservation (Santiapillai and Jackson 1990; Sukumar and Santiapillai 2006). Our study shows that the Anamalai landscape with a relatively large tract of about 4500 km² natural habitat has the potential to support a sizeable elephant population. Nevertheless, the network of canals and pipelines associated with hydro–electric projects especially in IGWLS and Theni Forest Division, and widespread human settlements/cultivation and commercial plantations over ~1000 km² across the landscape mostly in Valparai plateau, embedded within the southwestern part of IGWLS and Munnar Forest Division have created bottlenecks for the movement of elephants and, in some places, completely obstructed their passage.

The elephant population in the Anamalai landscape has access to a wide variety of forest types ranging from tropical climax grassland habitats and stunted evergreen forests at high elevation, to tropical evergreen and semi-evergreen forests at mid to low elevation in the west, tropical moist and dry deciduous forests at mid-elevations, and tropical dry thorn forest in the lower, eastern

part of the landscape. Further, the major part of the non-forest areas of the landscape that is planted with tea and cardamom (that are perennial in nature, with some canopy cover) are still being used by elephants for moving between forest patches, with negligible damage to these crops but occasional deaths of people.

In the tropical region, forage resource quality and quantity change significantly within a season between habitat types. This diversity of habitats and changing phenology are important for wide ranging species like elephants that are known to move seasonally between habitats due to their large foraging and specific nutritional requirements (Sukumar 1989; Baskaran 1998). Indeed, such a mosaic of habitat types could be responsible for the high density of elephants seen in the Western Ghats. Nevertheless, a considerable portion (594 km²) of the land is under monoculture forest plantations, mainly teak. Studies on elephant habitat use in this landscape (Baskaran et al. 2007) and elsewhere from northeastern India (Sukumar et al. 2003; Baskaran et al. 2004) have shown lower use of monoculture forest plantations over the natural forest habitats by elephants, due to the absence or lack of diverse forage plants in such plantations. These monocultures occupying a significant part of the total landscape could result in lower elephant abundance than what can otherwise be supported by the natural vegetation in the landscape.

Elephant population size and structure

The present estimate of overall density of 1.1 (95% CI=0.99–1.2) elephants/km² for the Anamalai landscape can be compared to the mean density of 0.82 (95% CI=0.67–0.99) elephant/km² estimated by dung count method during 2005 Elephant Census for the Kerala side of the landscape, predominantly in the western part (Sivaram et al. 2006). However, the density estimated by dung count method by the present study and also the 2005 elephant census of the forest department (Sivaram et al. 2006) are far higher than the 0.55 (95% CI=0.47–0.63) elephants/km² estimated by direct sighting, sample block count method during the 2005 elephant census in the Kerala part of landscape (Sivaram et al. 2006). This could be due to poor

visibility within tropical moist forest in the study area resulting in under-estimation of elephant density by the direct sighting method.

Elephant densities obtained from the dung survey, however, cannot be naively extrapolated to the potential elephant habitat area of each division as a part of this may be inaccessible and unused. While we have not estimated the effective elephant habitat area in this topographically complex landscape, we can attempt a crude figure on the basis of Sivaram et al. (2006) who use a figure of 2818 km² (or 68% of the forest division area) on the Kerala part of the landscape as effectively used by elephants. If this were also true for the combined Kerala and Tamil Nadu landscape, we arrive at a figure of 3960 km² as effective elephant habitat for the Anamalai landscape. The overall density of 1.1 (95% CI=0.99–1.2) elephant/km² would then translate into a figure of 4356 (95% CI=3920–4752) elephants for the landscape, a figure higher than earlier reported figures (2000 elephants: Sukumar et al. 1998; Bist 2002) or estimated by the elephant census in 2005 (2983 elephants). About 50 captive elephants kept in these forests must be excluded from the estimate of the wild elephant population.

The Anamalai landscape, harboring a sizeable elephant population with higher genetic (mt DNA) diversity than that of the larger Nilgiri population (Vidya et al. 2005), thus appears viable for long-term conservation according to the criteria of Leimgruber et al. (2003), provided that future developmental activities do not cause further habitat fragmentation. However, about 225 (CI=133–278) elephants (of 4356 elephants in the landscape) that range in Idukki Wildlife Sanctuary and the western part of Kothamangalam have to be considered as an isolated population as these elephants are unable to move to the larger landscape due to physical barriers associated with a hydro-electric dam as well as the presence of settlements and cultivation.

Further, the study showed that the sex ratio is skewed gradually toward females from juvenile (1:1.8) to sub-adult (1:2.4) and adult (1:14.7) indicating higher mortality of males, especially in the sub-adult and adult age classes of the population, which can be explained by historical poaching for tusks (Sukumar 1989, 2003). The sex ratio recorded in this study, though based on a small sample size ($n=89$), shows lesser skew than that reported by Kumar et al. (2004b) for the adult segment (1 male:38 females) based on a sample size of 162 elephants from the Valparai Plateau, a restricted part of this landscape. This underscores the need for more detailed documentation of elephant demography in this landscape.

Elephant–human conflict

The primary assessment of elephant–human conflict and the secondary data on crop compensation, human casualties and elephant mortality due to conflict in various forest divisions revealed that conflict intensity varied significantly across the landscape. Conflict was significantly higher in forest divisions (especially IGWLS, Dindugul, Theni, Marayur and Munnar) on the eastern side of the landscape compared to those on the western side of the landscape. There could be several possible reasons for this variation in conflict across the landscape. First, forest divisions on the eastern side had higher number of non-forest elements such as human settlements and cultivated land as compared to the western side. This loss and fragmentation of habitat, resulting in longer perimeter of forest area to cultivation, could bring relatively large numbers of elephants in contact with agriculture in the course of their seasonal movements (Sukumar 1989, 2003; Hoare 1999). Second, the greater anthropogenic impacts such as cattle grazing and fuel wood collection on forests in the eastern side (Kumar et al. 2002), could also perhaps further drive elephants to crop raiding more frequently here as reported elsewhere (Kumar et al. 2004b).

Third, the possible greater extent of cultivation of highly palatable annual crops (as inferred from the percentage of farmers cultivating annual crops) in the eastern side could also be a reason for the higher degree of conflict (Sukumar 1989). The quadratic relationship between this variable and conflict intensity, however, needs an explanation. The initial increase in conflict incidence with greater area under annual crops suggests that this could be due to increased attraction of elephants to such fields, but eventually “predator satiation” would serve to stabilize and perhaps even slightly reverse this trend. Thus, fewer farmers would suffer from crop damage in extensively cultivated areas. Overall, the results suggest that perimeter of a forest division (a metric of the extent of forest/cultivation interface) and percentage of farmers cultivating annual crops (a metric of palatable crop availability) are the major driving factors of elephant–human conflict in this landscape.

Recommendations

Overall, the study shows that the Anamalai landscape may support over 4000 elephants, ranging over about 4500 km² of diverse habitat types. However, a small part (5%) of the population is certainly isolated at Idukki and a part of Kothamangalam Forest Division owing to land-use and topographical constraints. The sex ratio is skewed toward females in the higher age-classes indicating the influence of past ivory poaching. A higher proportion of non-forest elements on the eastern side of the landscape has resulted in several bottlenecks to the movement of elephants and greater elephant–human conflict as compared to the western side. We make the following broad recommendations to conserve the Anamalai elephant population along with its rich biodiversity.

- (1) Increased connectivity of elephant habitats, especially in the Munnar, Marayur and IGWLS (Valparai plateau), is needed to reduce elephant–human conflicts and facilitate easier movement of elephants through corridors. This can be achieved through economic incentives to farmers and private plantation owners to allow movement of elephants through their land (or a designated part) as well as possible change of land use to forest plantations. Unlike many of the much older commercial plantations in this region, the Ryan Tea Estate was opened relatively recently (1990–95) by clearing natural forest in the plateau and has experienced high levels of elephant–human conflict (Kumar et al. 2010). As a first step, the government has ordered (on April 4, 2012) that 128 ha of this government-owned plantation in the Valparai plateau to be handed back to the administration of the Tamil Nadu Forest Department for conversion into mixed forest plantation.
- (2) Legal options for preventing or regulating land-use change within and close to elephant corridors may also be explored to ensure long-term connectivity. The declaration of Ecologically Sensitive Areas under the country's Environmental Protection Act of 1986 is one such option, as is the declaration of buffer zones around Protected Areas.
- (3) Thinning of existing monoculture forest plantations, a sub-optimal habitat, to improve regeneration of diverse native plants and the forage availability to the elephant population.
- (4) An integrated land-use policy for the cultivated land within and around the landscape through advocating cultivation of crops appropriate for the region, especially those unpalatable to elephants to reduce elephant–human conflict.
- (5) An integrated landscape and population level management approach (habitat management, protection against ivory poaching and population monitoring) for coordinating elephant conservation with neighboring forest divisions and states.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.mambio.2013.04.007>.

References

- Arivazhagan, C., Sukumar, R., 2008. Constructing age structures of Asian elephant populations: a comparison of two field methods of age estimation. *Gajah: Journal of the Asian Elephant Specialist Group* 29, 11–16.
- Barnes, R.F.W., Jensen, K.L., 1987. How to count elephants in the forest. *IUCN African Elephant and Rhino Specialist Group Technical Bulletin* 1, 1–16.
- Barnes, R.F.W., 1993. Indirect method for counting elephants in forest. *Pachyderm* 16, 24–30.
- Baskaran, N., 1998. Ranging and resource utilization by Asian elephant (*Elephas maximus* Linn.) in Nilgiri Biosphere Reserve South India. Bharathidasan University, Tiruchirappally, India (Ph.D. Thesis).
- Baskaran, N., Balasubramanian, M., Swaminathan, S., Desai, A.A., 1995. Home range of elephants and its implications for the management of Nilgiri Biosphere Reserve India. In: Daniel, J.C., Datye, H.S. (Eds.), *A Week with Elephants*. Bombay Natural History Society and Oxford University Press, Bombay, pp. 296–313.
- Baskaran, N., Harshad, R.M., Sukumar, R., 2004. A study on elephant population and its habitats in the northern West Bengal, northeastern India. Technical Report, Asian Elephant Research and Conservation Centre, Centre for Ecological Sciences, Indian Institute of Science, Bangalore.
- Baskaran, N., Kannan, G., Anbarasan, U., 2007. Conservation of elephant population in the Anamalai–Nelliampathi & Palani hills (Project Elephant Range 9), southern India. In: Final Report to United States Fish & Wildlife Service. Asian Nature Conservation Foundation, c/o Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India.
- Bist, S.S., 2002. An overview of elephant conservation in India. *The Indian Forester* 128 (2), 121–136.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Lake, J.L., 2003. *Distance Sampling: Estimating Abundance of Biological Populations*. Chapman & Hall, London.
- Burnham, K.P., Anderson, D.R., 2002. *Model Selection and Multi-model Inference: A Practical Information – Theoretical Approach*, 2nd ed. Springer.
- CITES UNEP-WCMC, 2003. UNEP-WCMC Species Database: CITES Listed Species on the World Wide Web, <http://www.cites.org/eng/resources/species.html> (accessed on 01.05.03).
- Congalton, R., Green, K., 1999. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. CRC/Lewes Press, Boca Raton, 137pp.
- Dawson, S., 1990. A model to estimate Asian elephant densities in forest. Department of Zoology, University of Oxford (M.Sc., Dissertation). 135 pp.
- Dawson, S., Dekker, A.J.F.M., 1992. Counting Asian Elephants in Forests. RAPA Publication: 1992/11. FAO, Bangkok, Thailand.
- Desai, A.A., 1991. The home range of elephants and its implications for the management of the Mudumalai Wildlife Sanctuary, Tamil Nadu. *J. Bombay Nat. Hist. Soc.* 88, 145–156.
- Easa, P.S., Zacharias, J., Indichoodan, N.C., 1990. A conservation unit for Asian elephant. In: Karunakaran, C.K. (Ed.), *Proceedings of the Symposium on Ecology, Behaviour and Management of Elephants in Kerala*. Thiruvananthapuram, 23–24 February 1990. Wildlife Wing, Kerala Forest Department, pp. 149–157.
- Gadgil, M., Meher-Homji, V.M., 2003. Conservation in developing countries: problems and prospects. In: Daniel, J.C., Serrao, J.S. (Eds.), *Proceedings of the Centenary Seminar of the Bombay Natural History Society*. Bombay Natural History Society, pp. 175–198.
- Hedges, S., Lawson, D., 2006. Monitoring the Illegal Killing of Elephants: Dung Survey Standards for the MIKE Programme. CITES MIKE Programme Central Co-ordinating Unit, Nairobi, Kenya.
- Hoare, R., 1999. Determinants of elephant–human conflict in a land-use mosaic. *J. Appl. Ecol.* 36 (5), 689–700.
- IUCN, 2010. IUCN Red List of Threatened Species. Version 2010.4, <http://www.iucnredlist.org> (downloaded on 06.01.11).
- Jensen, J.R., 2007. *Remote Sensing of the Environment: An Earth Resource Perspective*, 2nd ed. Prentice Hall, Upper Saddle River, NJ.
- Kannan, R., 1998. Avifauna of the Anamalai hills (Western Ghats) of southern India. *J. Bombay Nat. Hist. Soc.* 95, 193–214.
- Kumar, A., Singh, M., Srivastava, S.K., Udhayan, A., Kumara, H.N., Sharma, A.K., 2002. Distribution patterns, relative abundance and management of mammals in Indira Gandhi Wildlife Sanctuary, Tamil Nadu, India. *J. Bombay Nat. Hist. Soc.* 99, 184–210.
- Kumar, A., Pethiyagoda, R., Mudappa, D., 2004a. Western Ghats and Sri Lanka. In: Mittermeier, R.A., Gill, P.R., Hoffman, M., Pilgrim, J. (Eds.), *Hotspots Revisited – Earth's Biologically Richest and Most Endangered Ecoregions*. CEMEX, Mexico, pp. 152–157.
- Kumar, M.A., Mudappa, D., Raman, T.R.S., Madhusudan, M.D., 2004b. The Elephant Hills. Conservation of wild Asian elephants in a landscape of fragmented rainforests and plantations in the Anamalais, India. CERC Technical Report No. 10. Nature Conservation Foundation, Mysore.
- Kumar, M.A., Mudappa, D., Raman, T.R.S., 2010. The Asian elephant *Elephas maximus* habitat use and ranging in fragmented rainforest and plantations in Anamalai hills, India. *J. Conserv. Sci.* 3 (2), 143–158.
- Laing, S.E., Buckland, S.T., Burn, R.W., Lambie, D., Amphlett, A., 2003. Dung and nest surveys: estimating decay rates. *J. Appl. Ecol.* 40, 1102–1111.
- Leimgruber, P., Gagnon, J.B., Wemmer, C., Kelly, D.S., Songer, M.A., Selig, E.R., 2003. Fragmentation of Asia's remaining wild lands: implications for Asian elephant conservation. *Anim. Conserv.* 6, 347–358.
- Lillesand, T.M., Kiefer, R.W., 2000. *Remote Sensing and Image Interpretation*, 4th ed. John Wiley and Sons Inc., Singapore.
- Mar, K.U., 2007. The demography and life history strategies of timber elephants in Myanmar. University College, London (Ph.D. Thesis).
- Mittermeier, R.A., Gill, P.R., Hoffman, M., Pilgrim, J., 2005. *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*. Cemex, Mexico, pp. 136–147.
- Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. *Nature* 403, 853–858.
- Nameer, P.O., Molur, S., Walker, S., 2001. Mammals of Western Ghats: a simplistic overview. *Zoos' Print* 16, 629–639.
- Pascal, J.P., Shyam-Sunder, S., Meher-Homji, V.M., 1982. Forest Map of South India: Mercara-Mysore. Karnataka Forest Department Bangalore and French Institute Pondichery.
- Project Elephant, 2004. Ministry of Environment and Forests. Government of India, New Delhi.
- Project Elephant: Gajatme, 1993. Project Elephant, Ministry of Environment and Forest, Government of India. February 1993.
- Rangarajan, M., Desai, A., Sukumar, R., Easa, P.S., Menon, V., Vincent, S., Ganguly, S., Talukdar, B.K., Singh, B., Mudappa, D., Chowdhary, S., Prasad, A.N., 2010. *Gajah: Securing the future for elephants in India*. Report of the Elephant Task Force. Ministry of Environment and Forests, New Delhi, 187 pp.
- Riddle, H.S., Schulte, B.A., Desai, A.A., Meer, L.V.D., 2010. Elephants – a conservation overview. *Journal of Threatened Taxa* 2 (1), 653–661.
- Santiapillai, C., Jackson, P., 1990. *The Asian Elephant: An Action Plan for its Conservation*. IUCN-The World Conservation Union, Gland, Switzerland.
- Santosh, J.A., Sukumar, R., 1995. Some solutions to estimation of elephant densities. In: Daniel, J.C., Datye, H.S. (Eds.), *A Week with Elephants*. Bombay Natural History Society and Oxford University Press, Bombay, pp. 394–404.
- Sivaram, M., Ramachandran, K.K., Nair, V.P., Jayson, E.A., 2006. Population estimation of wild elephants in the elephant reserves of Kerala state – 2005. KFRRI Extension Project Report No. 61. Kerala Forest Research Institute, Peechi.
- Subramanyam, K., Nayar, M.P., 1974. Vegetation and phytogeography of the Western Ghats. In: Mani, S. (Ed.), *Ecology and Biogeography of India*. W Junk Publishers, The Hague, The Netherlands, pp. 178–196.
- Sukumar, R., 1989. *The Asian Elephant: Ecology and Management*. Cambridge University Press, New York.
- Sukumar, R., 2003. *The Living Elephants: Evolutionary Ecology, Behavior and Conservation*. Oxford University Press, New York.
- Sukumar, R., Joshi, N.V., Krishnamurthy, V., 1988. Growth in the Asian elephant. In: *Proceedings of the Indian Academy of Science (Animal Sciences)* 97, pp. 561–567.
- Sukumar, R., Krishnamurthy, V., Wemmer, C., Rodden, M., 1997. Demography of captive Asian elephants (*Elephas maximus*) in southern India. *Zoo Biol.* 16, 263–272.
- Sukumar, R., Santiapillai, C., 2006. Planning for Asian elephant conservation. *Gajah: Journal of the Asian Elephant Specialist Group* 25, 9–20.
- Sukumar, R., Venkataraman, A., Varma, S., Kumar, V., 1998. *The Asian Elephant in Southern India: A GIS Database for the Conservation of Project Elephant Reserves*. Asian Elephant Research and Conservation Centre, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India.
- Sukumar, R., Venkataraman, A., Baskaran, N., Dharmarajan, G., Roy, M., Suresh, H.S., Narendran, K., December 2003. Study of elephants in Buxa Tiger Reserve and adjoining areas in northern west Bengal and preparation of conservation action plan. In: Final Report to the West Bengal Forest Department under India Eco-development Project. Centre for Ecological Science, Indian Institute of Science, Bangalore.
- Thomas, L.J., Laake, L., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Hedley, S.L., Pollard, J.H., Bishop, J.R.B., Marques, T.A., 2005. DISTANCE, version 5.0, beta 5. Research Unit for Wildlife Population Assessment, University of St. Andrews, United Kingdom, Available at <http://www.ruwpa.st-and.ac.uk/distance/> (online).

- Umapathy, G., Kumar, A., 2000. Occurrence of arboreal mammals in the rain forest fragments in the Anamalai hills, South India. *Biol. Conserv.* 92, 311–319.
- Venkataraman, A., 2005. What is an Asian elephant (*Elephas maximus*) corridor? In: Menon, V., Tiwari, S.K., Easa, P.S., Sukumar, R. (Eds.), *Right of Passage: Elephant Corridors of India*. Wildlife Trust of India, New Delhi, pp. 24–33.
- Vidya, T.N.C., Fernando, P., Melnick, D.J., Sukumar, R., 2005. Population differentiation within and among Asian elephant (*Elephas maximus*) populations in southern India. *Heredity* 94, 71–80.
- Watve, M.G., 1992. Ecology of host parasite interactions in wild mammalian host community in Mudumalai, southern India. Indian Institute of Science, Bangalore (Ph.D. Thesis).