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Ecology of the Asian elephant in southern India. I. Movement and habitat utilization patterns

R. SUKUMAR

Centre for Ecological Sciences, Indian Institute of Science, Bangalore – 560 012, India

ABSTRACT. The movement and habitat utilization patterns were studied in an Asian elephant population during 1981-83 within a 1130 km² area in southern India (11° 30′ N to 12° 0′ N and 76° 50′ E to 77° 15′ E). The study area encompasses a diversity of vegetation types from dry thorn forest (250-400 m) through deciduous forest (400-1400 m) to stunted evergreen *shola* forest and grassland (1400-1800 m).

Home range sizes of some identified elephants were between 105 and 320 km². Based on the dry season distribution, five different elephant clans, each consisting of between 50 and 200 individuals and having overlapping home ranges, could be defined within the study area. Seasonal habitat preferences were related to the availability of water and the palatability of food plants. During the dry months (January-April) elephants congregated at high densities of up to five individuals km^{-2} in river valleys where browse plants had a much higher protein content than the coarse tall grasses on hill slopes. With the onset of rains of the first wet season (May-August) they dispersed over a wider area at lower densities, largely into the tall grass forests, to feed on the fresh grasses, which then had a high protein value. During the second wet season (September-December), when the tall grasses became fibrous, they moved into lower elevation short grass open forests.

The normal movement pattern could be upset during years of adverse environmental conditions. However, the movement pattern of elephants in this region has not basically changed for over a century, as inferred from descriptions recorded during the nineteenth century.

KEY WORDS: Asian elephant, elephant ecology, *Elephas maximus*, habitat utilization, home range, India.

INTRODUCTION

A study on the ecology of the Asian elephant (*Elephas maximus* Linnaeus) in relation to its interaction with people in southern India was carried out during 1981-83 (Sukumar 1985). Among other aspects, the interrelationships of movement pattern, feeding habits and raiding of agricultural crops were investigated. This paper gives the necessary background description of the study area and analyses movement and habitat utilization patterns of elephants. A sequel will describe the elephant's feeding habits and depredation on crops in the course of their seasonal movement as part of their optimal foraging strategy (Sukumar, in press).

STUDY AREA

The study area is situated between 11° 30′ N to 12° 0′ N and 76° 50′ E to 77° 15′ E (Figure 1). It comprises a forested area of 1130 km² spread over the Chamarajanagar, Kollegal and Satyamangalam Forest Divisions in southern India. The cultivated enclaves occupy an additional 70 km² within the study area.

From the Mysore plateau with an average elevation of 750 m, the Biligirirangan hills rise a further 1000 m. The two central chains of hills, running from north to south, feature a number of peaks above 1500 m, which present a vista of grasslands and evergreen *shola* (= grove) vegetation. The enclosed valleys contain moist deciduous forest. Both to the east and to the west, the lower hills and valleys from 1250 m to 750 m become progressively drier the further away from the central ranges, with dry deciduous forest changing into degraded scrub. To the south the hills drop steeply to the Coimbatore plains and the Moyar river valley (250 m), where a strip of dry thorn forest is found at the foothills. South of the Moyar river rises the Nilgiri mountain range (highest

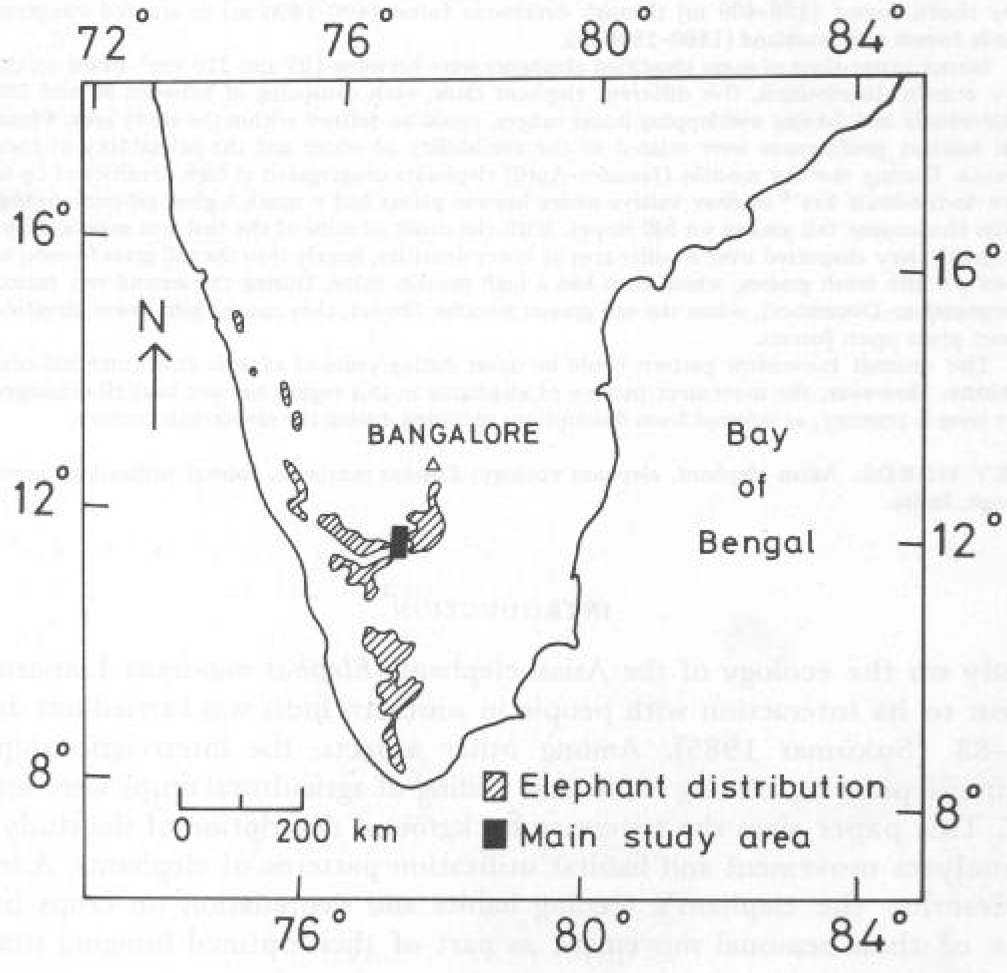

Figure 1. Map showing elephant distribution in southern India and location of the main study area.

peak 2636 m) which forms part of the great Western Ghat chain of peninsular India. Geologically, the entire region is formed by the Archean group of rocks, mainly the gneisses.

Hydrology

The region has two drainage systems - a major one emptying into the Cauvery river and a minor one into the Moyar river. Given a general northwards aspect in this area, most of the streams ultimately reach the Cauvery which flows in an eastward direction to the north of the Biligirirangan hills. The hills are separated from this perennial river by a cultivated tract. Among the important streams are the Nirdurgi and the Araikadavu. At their junction the waters are impounded by the Suvarnavati Reservoir (4 km^2 submersion area), an irrigation project. To the south a few streams drain into the perennial Moyar river, though their contributions are insignificant. The bulk of the waters of the Moyar originates in the Nilgiris. The Moyar discharges into the Lower Bhavani Reservoir (80 km^2 submersion area), an irrigation cum hydroelectric project.

Climate

The study area shows a striking diversity of climate due to the varied relief and topography. Absolute maximum and minimum temperatures range from 40°C (250 m) during April to below 0°C in the open grasslands (>1600 m) during December-January. Average annual rainfall similarly varies from 50 cm to 185 cm at these locations respectively. Monthly rainfall at Hasanur (900 m) is shown in Figure 2. During the study period, rainfall was normal over the area in 1981. In 1982 the area received only about half the normal rainfall.

More than any other climatic factor it is the availability of water (both its direct availability for consumption and its impact on the vegetation) that determines the elephants' seasonal cycles. Based mainly on the rainfall pattern and water availability in the environment, three broad seasons were defined for the purpose of this study.

(a) Dry season (January-April)

This period is characterized by negligible rainfall during January and February. Though there is some rain in March and April, this is still a period of 'hydrological drought', i.e. low stream flow and pond levels as defined by Von Lengerke (1977).

(b) First rainy or wet season (May-August)

The heavy pre-monsoon showers in May and the subsequent influence of the SW monsoon until August bring about a quantitative change in water availability. Rainfall attains a peak in August at the higher altitudes to the north of the study area.

(c) Second rainy or wet season (September-December)

Before the end of the SW monsoon there is a sharp increase in rainfall over

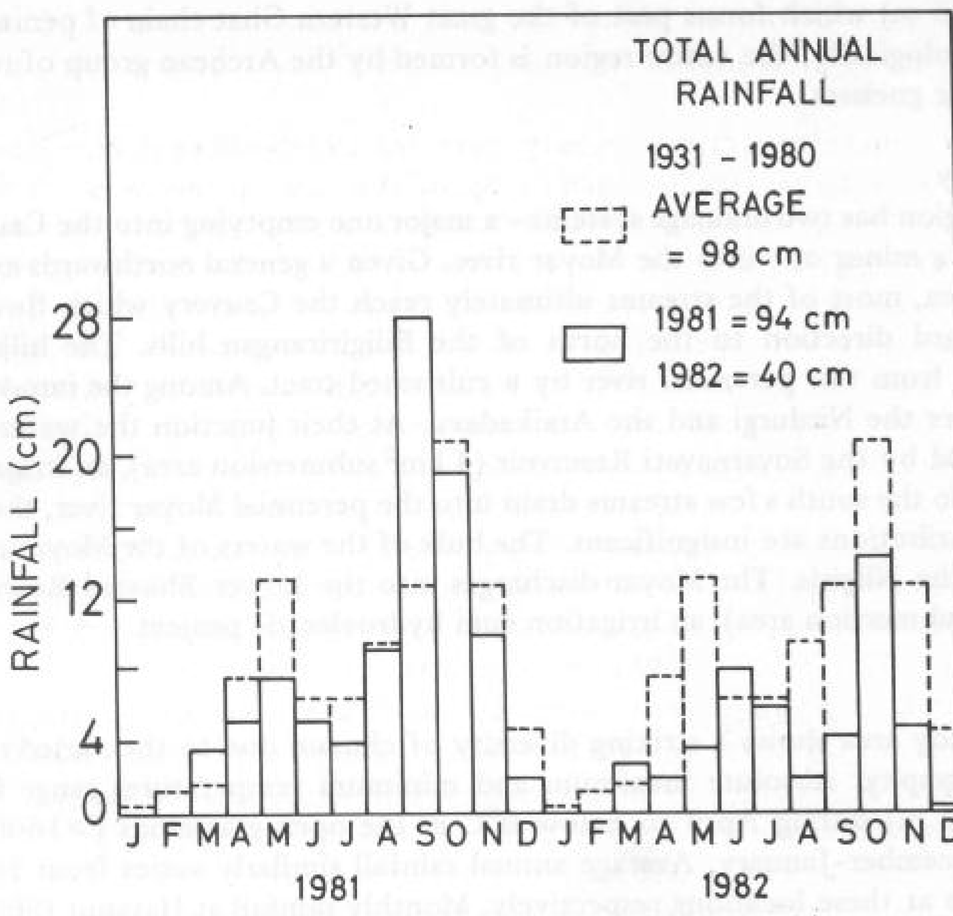

Figure 2. Monthly rainfall at Hasanur (900 m altitude).

the southern part of the area, with a peak in October or sometimes September. Although rainfall from the NE monsoon is irregular during November and December, sufficient water is available in the streams and ponds.

Land use pattern

The area has been inhabited for many centuries by the Sholaga tribes who earlier practised shifting cultivation on the hills. Later, portions of the fertile valleys and plateaux were brought under permanent cultivation, depending largely on the rains. Higher altitude hill slopes (>1250 m) in the central portion have been taken over for coffee plantations. In recent years the state forest departments have raised plantations of eucalypts (*Eucalyptus* spp.) and, to a lesser extent, teak (*Tectona grandis* L. f.) and silver oak (*Grevillea robusta* A. Cunn.). This area has been a source of numerous products including timber, fuel wood, pulp wood and a variety of minor products such as fruits, bark and honey. Sandalwood (*Santalum album* L.) is an especially valuable commodity. Large herds of domestic livestock (density of 28 km^{-2} depend on the forest land for grazing.

Vegetation types

The basic tropical vegetation types as defined by Puri (1960) include montane stunted evergreen *shola* forest and grassland (78 km^2), moist deciduous forest

(157 km^2), dry deciduous forest (756 km^2) and dry thorn forest (106 km^2). In addition, many plantation forests (about 73 km^2) are scattered over different habitats.

Due to human impact the primary forest has largely changed into secondary forms. For instance, due to opening up of the canopy the moist deciduous forest now exists only as an intermediate between the primary moist and the primary dry deciduous types. The dry deciduous forest has been degraded into scrub in areas around cultivation. The study area was divided into 19 zones based on vegetation type, secondary stages, species composition, topography, altitude, location and other natural features such as streams (Figure 3). The principal features of these zones are summarized in Appendix I. For the purpose of studying the elephant's pattern of habitat utilization in relation to feeding it was useful to classify the zones into these broad habitat types.

(a) Short grass areas with predominantly browse vegetation (Zones 1, 7, 8, 9, 10, 12, 18 and 19, total area = 398 km^2, entire area accessible).

(b) Mixed tall grass and browse in deciduous forest (Zones 2, 3, 5, 6, 11, 13, 14, 15 and 17, total area = 642 km^2, accessible area = 475 km^2).

(c) Lowland grassland (only Zone 16 which has been partly modified by plantations but taken as representative, area = 12 km^2, entirely accessible).

(d) Montane stunted evergreen *shola* forest and grassland (Zone 4, total area = 78 km^2, accessible area = 53 km^2).

The total area of a particular habitat is not necessarily accessible to elephants. For instance, a large proportion of the steep slopes of Zones 2 and 17 is not readily negotiable. Therefore, the accessible area is also given for making an unbiased comparison.

METHODS

Movement and habitat utilization patterns in African bush elephant (*Loxodonta africana* Blumenbach) populations have been studied by aerial counts to determine seasonal distribution and by radio-tracking of individual elephants (e.g. Douglas-Hamilton 1972, Eltringham 1977, Laws *et al.* 1975, Leuthold 1977). Counting elephants from an aircraft is impossible in most Asian elephant habitats due to the forested canopy. Facilities for radio-tracking were not available for this study. Alternative methods had to be used to study movement patterns.

Re-sightings of identified elephants

A photographic file was maintained on elephant family groups and adult bulls. Elephants were identified by characteristics of their ears such as cuts, holes and degree of folding, and characteristics of tusks in males such as size, shape, broken tips, etc. (Douglas-Hamilton 1972). Instances of sightings of identified elephants were marked on a map. Peripheral locations of sightings were connected by straight lines to obtain the smallest convex polygon which contained all locations and the enclosed area was taken to be the home range (Jennrich & Turner 1969, Leuthold 1977).

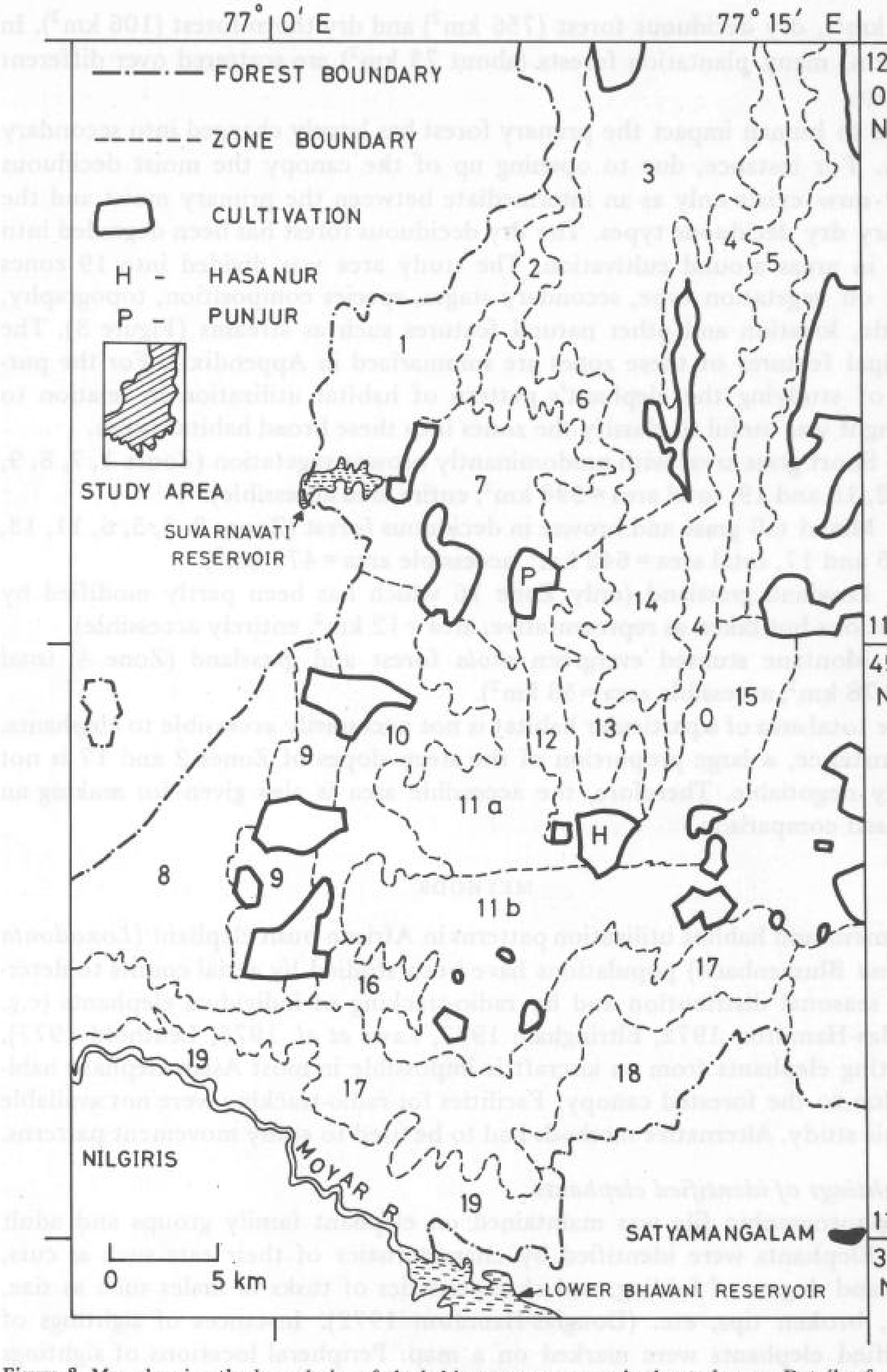

Figure 3. Map showing the boundaries of the habitat types or zones in the study area. Details of area and vegetation of the zones are given in Appendix I and the text.

Density estimates in different zones

The average elephant densities in different zones during two-month periods were determined by ground transects, details of which are given in Appendix II. The purpose was to get a picture of the spatial distribution patterns of elephants during different seasons, from which inferences could be made on broad movement patterns and strategy of habitat utilization.

RESULTS

Elephant densities and seasonal distribution patterns

Data on elephant densities in different zones covering 928 km^2 are presented in Appendix II. Elephant densities are depicted in Figure 4 to show the spatial distribution patterns during January-February, March-April, July-August and November-December. Except for January-February, the data have been combined for 1981 and 1982 since there was not much difference in the zonal density patterns during corresponding periods in these two years.

(a) Dry season distribution (January-April)

Certain riverine vegetation zones had the highest elephant concentrations during the dry season. Zone 12 had a density of about four elephants km^{-2} during 1981 and 1982 when some water was available in the Araikadavu stream. In the Moyar river valley (Zone 19) there was a high concentration during the early part of the dry season, but elephants began dispersing from March onwards. The thorn forest in the plains (Zone 18) was also utilized intensively during January-February but not afterwards.

Considerable numbers of elephants were also present in some of the tall grass forests. The grassland Zone 16 and the deciduous forests of Zone 11B had high to medium densities during January-February, while Zones 3 and 6 had medium densities in March-April. All other zones showed a low density or absence of elephants during this season.

(b) First wet season distribution (May-August)

After the pre-monsoon showers in April-May, elephants dispersed from the riverine habitats occupied during the dry months. For instance, in Zone 12 there was a sharp fall in density to between 0.5 and 1.0 elephants km^{-2}, a mere fraction of the dry season concentration. There were few elephants in the Moyar river valley (Zone 19) during May-August. But elephants utilized one riverine habitat (Zone 7) at a higher intensity than earlier.

The tall grass forest zones now experienced an influx of elephants. This was most noticeable in the deciduous forests of Zones 3 and 6, where a density of 1-2 elephants km^{-2} was reached. Since elephants were now diffused over a wider area, no single zone had very high densities such as occurred during the dry season. There was also evidence that between May and August the total number of elephants in the main study area was reduced due to movement to

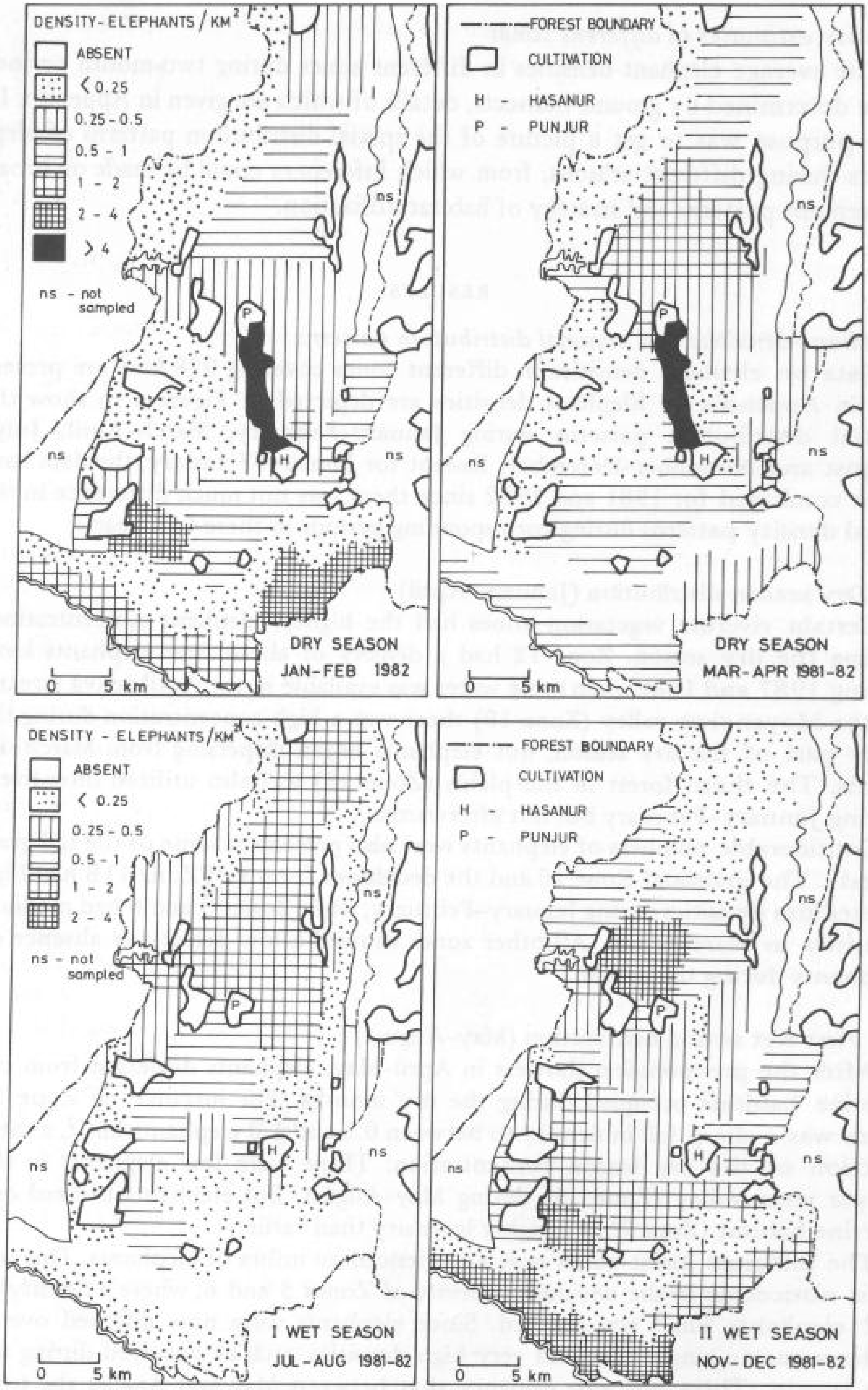

Figure 4. Seasonal distribution patterns of elephants.

outside areas. Such a seasonal excursion was mainly from the Moyar valley southwards and westwards into the Nilgiri hills.

(c) Second wet season distribution (September–December)

Beginning in September there was a distinct movement from Zone 3 southwards into the lower elevation short grass habitat of Zone 7. Elephants also increasingly occupied the scrub woodlands of Zones 8 and 10. In late October there began an influx into the Moyar valley from the Nilgiris and probably also from the north through a few passes in the steep hills.

In September–October the situation was still somewhat diffuse, but by November–December certain well-defined concentrations could be seen. These included a high density of 2–4 elephants km^{-2} in Zone 7 and Zone 19, and about 2 elephants km^{-2} in Zone 16 and adjacent areas of Zones 8 and 11 B. Elephants also moved into Zone 18 beginning in November.

Movement pattern of different clans and home range sizes

Based on the dry season distribution, certain distinct clusters of numerous elephant families could be identified in different regions of the study area. These aggregations were similar to the 'clans' described for the African elephant (Douglas-Hamilton 1972, Laws *et al.* 1975, Moss 1982). These clans probably consist of many related elephant families (as presumed in the African species) though no firm evidence for this can be presented here. Each clan consisted of about 50 to 200 individuals as inferred from the density estimates in zones where such aggregations occurred. Families of a clan seemed broadly coordinated in their movement pattern. In the absence of radio-tracking data about the specific movement of any clan only their general movement pattern can be described, based on re-sightings of identified elephants and indirect inference from seasonal distribution.

Clan 1. During January many of these elephants began moving from Zone 7 and other lower regions into the hilly Zones 6 and 3, which they occupied until the second wet season. In September–October they moved out of the denser forests into more open areas at lower elevation. They congregated especially in Zone 7 during November–December.

Clan 2. In January these elephants were seen largely in the southern Zone 11B and moved north during February–March into Zone 12 which they utilized intensively for the rest of the dry season. During the first wet season they dispersed from Zone 12, but the main direction of movement was still northwards into Zone 7. During the second wet season they moved south presumably through Zones 10 and 11A into Zones 11B and 16.

Clan 3. This comprised elephants which congregated in Zone 16 and adjacent areas of Zones 8, 9, 10 and 11B during November–February. The exact nature of their movement was not known. During March–October they may have largely moved outside the study area.

Clan 4. Perhaps more than one clan, i.e. a sub-population, moved into the

Moyar valley (Zone 19) during the second wet season in October. Beginning in March, when the dry spell had not yet broken, they began dispersing from this river valley into the Nilgiri hills.

Clan 5. Not much was known about the movement of this clan which largely occupied Zones 5, 14 and 15.

The home range sizes of family herds of Clan 1 and Clan 2 were about

Table 1. Re-sightings and home range sizes of elephants.

Elephants	Number of identified sightings	Zones in which recorded	Time (months) (a) Between farthest re-sightings	Time (months) (b) Between first and last sighting	Linear distance of farthest re-sighting (km)	Home range size (km^2)
Adult bull (MA - 6)	11	9, 11, 12, 16 and in cultivation	7.3	19.5	21	170
Adult bull (MA - 19)	12	19, also in Mudumalai and Bandipur to west of main study area	5.2	26.0	52	320
Adult bull (MA - 25)	7	8, 9, 10 and in cultivation	3.0	9.3	20	215
Family herd (Clan 1)	14	3, 6, 7	16.4	23.5	25	105
Family herd (Clan 2)	15	7, 11, 12, 16	18.0*	23.2	21*	115

* A movement of 17 km within 4 months was also recorded.

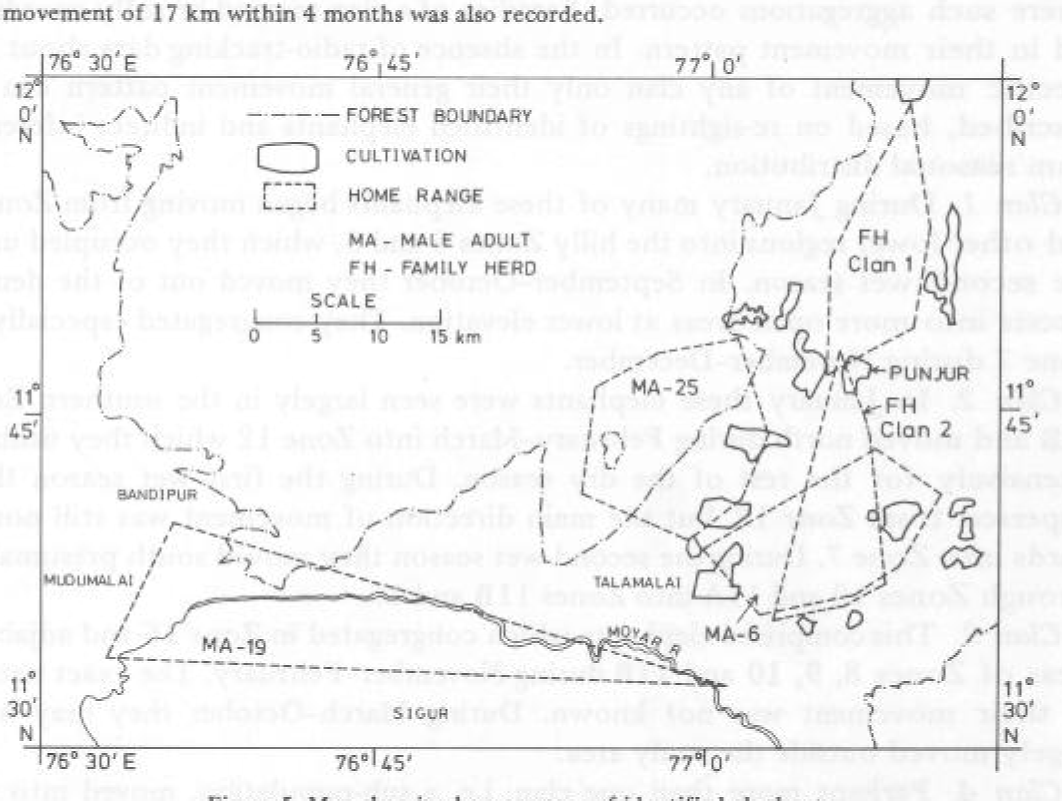

Figure 5. Map showing home ranges of identified elephants.

105 km^2 and 115 km^2 respectively (Table 1 and Figure 5). Since the other clans moved out of the study area their home range sizes could not be determined. For three identified adult bulls, the home range sizes were 170 km^2 (Ma-6), 320 km^2 (MA-19) and 215 km^2 (MA-25).

Annual differences in movement pattern

When environmental factors, especially rainfall, show any drastic changes, the normal movement pattern could be upset. Evidence for this came from the dry season elephant distribution of 1983. The patterns described so far were largely true for 1981 and 1982. In 1982 the annual rainfall was only about half the normal amount. Environmental effects were not evident immediately, but later the dry season of 1983 was an especially harsh period.

During the normal years a very high elephant concentration was seen between January and April in Zone 12 (Appendix II). In 1983 there was practically no water in the Araikadavu stream in these months. During January–February 1983 the density of 1.4 elephants km^{-2} was much lower than the 1982 density of 5.0 km^{-2}. By March–April 1983 there were hardly any elephants in the area as the following comparison reveals:

	Density of elephants km^{-2} in Zone 12	
Year	*January–February*	*March–April*
1981	Not sampled	4.3
1982	5.0	3.7
1983	1.4	0.3

Correspondingly, during March–April there was an increase in elephant concentration in the northern part of Zone 3, where a perennial pond became an important water source. Since these changes in distribution occurred at the end of the study, the specific shift in habitat of the clans involved could not be determined.

Seasonal use of habitat types

The mean elephant density in the study area was 0.56 km^{-2} in 1981 and 0.53 km^{-2} in 1982. Thus, for a given zone a seasonal density higher than about 0.5 km^{-2} indicates a greater than expected use and a lower density a lower than expected use (see Appendix II for density values). Habitat use can also be considered for the broader vegetation types. The proportion of elephants in these habitat types in relation to the area available during 1982 is shown in Figure 6.

During the early part of the dry season (January–February) the short grass habitats were clearly used more than their proportional availability. This declined progressively with the onset of pre-monsoon showers (March–April). During the first rainy season (May–August) the deciduous forests with tall

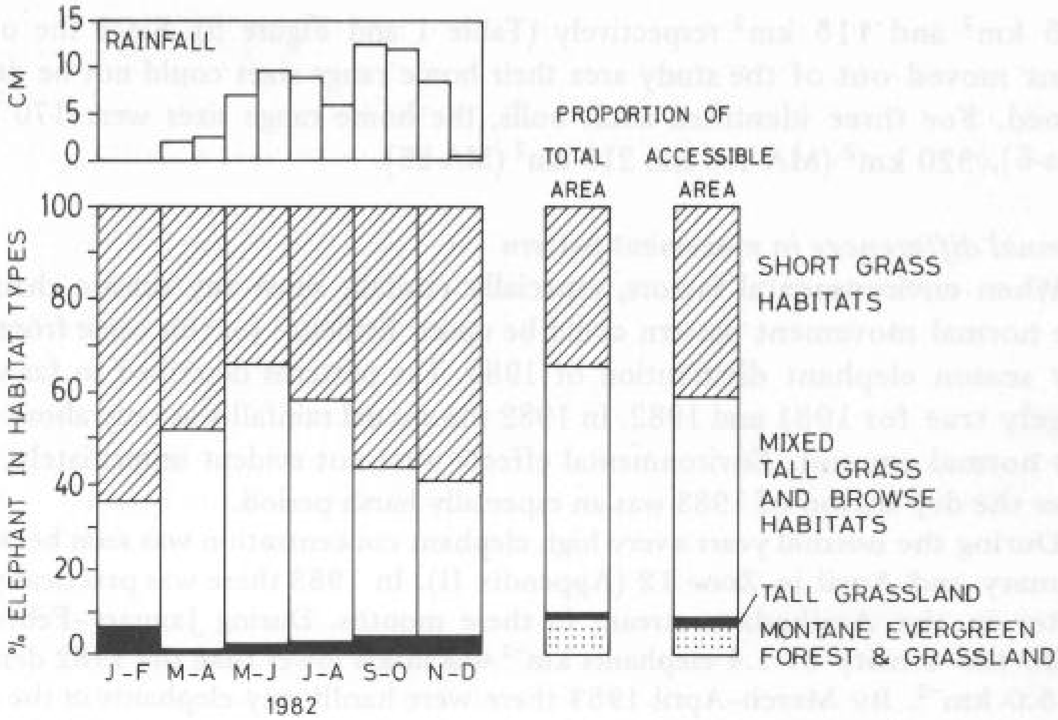

Figure 6. Seasonal use of major habitat types by elephants. The average rainfall of three stations is given.

grasses were generally preferred. But after the second heavier rains (September–December) elephants moved once again largely into the short grass open habitats. High altitude evergreen *shola* forest and grassland were largely shunned. They were utilized to a negligible extent throughout the year. However, in another elephant region, the Nilgiris, it was noticed that elephants utilized this vegetation type to a greater extent during the dry months. The lowland grassy areas such as parts of Zone 16 were used in greater proportion than availability. In the adjacent Mudumalai sanctuary, a similar preference for the swampy grasslands was noticed during the dry season.

DISCUSSION

Factors influencing home range size

While it can be intuitively expected that an animal's range of movement would increase with greater body size and energy requirement (McNab 1963), the predictive equations in the literature (Mace *et al.* 1983, Peters 1983) give no indication of the enormous variation in home range size of a species such as the elephant. The following broad patterns can be seen with regard to factors influencing the range sizes of different elephant populations.

(a) Home range sizes of only 14 to 52 km^2 for the African elephant at Lake Manyara National Park, Tanzania (Douglas-Hamilton 1972), seem to be imposed by barriers to free movement.

(b) The unpredictable availability of water in semi-arid zones may contribute to relatively large home ranges. In the dry Tsavo region of Kenya, range sizes of over 2000 km^2 have been reported (Leuthold 1977).

(c) In areas where water is not a limiting resource, the availability of food may govern the home range size. In the rain forests of Malaysia, Olivier (1978) found that the home range size of family groups is larger in primary forest (up to 167 km^2) where food plants are less abundant than in secondary forest (up to 59 km^2).

(d) The diversity in habitat types may also influence range size. The more diverse a region, the smaller could be the home range since elephants would be able to meet their varied seasonal requirements within a relatively restricted area.

The elephants in the study area are part of a larger population distributed over a contiguous area of 10,000 km^2. The estimated home ranges of about 100 to 300 km^2 should be regarded as minimum sizes. Leuthold (1977) found that home range sizes determined by radio-tracking were usually larger than that revealed by visual identification.

Movement in relation to optimal foraging and availability of water

The theory of optimal foraging has been developed for movements of foraging animals (Pyke 1983, Sinclair 1983). The observations on movement patterns in the study area certainly suggest that elephants largely optimize their food intake. A more detailed consideration of what constitutes the optimal diet along with nutrient values of food plants is available elsewhere (Sukumar 1985) and will be presented in a subsequent paper (Sukumar, in press). Here, only one aspect of diet in relation to movement will be mentioned.

(a) During the dry season, browse plants have a higher crude protein content (6-18% dry weight) than grasses (1.5-2.5% in the basal portion consumed during this season). Hence, elephants could be expected to show a preference for the predominantly browse vegetation zones, and also for browse plants within the tall grass forests. As seen in Figure 5 they clearly utilize the browse habitats in greater proportion than availability.

(b) After the onset of rains, the tall grasses become highly palatable (8-10% protein) for a few months, especially in the fire burnt areas. As expected, elephants show a distinct movement into the tall grass forests during the first wet season to feed mainly on grass.

(c) During the second wet season, when the tall grasses turn fibrous and siliceous with a lower palatability and protein content (2-4% in the basal portion), elephants again increasingly utilize the short grass habitats.

At the overall level, the strategy of habitat utilization conforms to the predictions of optimal foraging theory. However, elephants need not just food but also water in large quantities. Their movement would also be governed by the spatial distribution and temporal availability of water. Studies on the seasonal distribution of the African elephant have shown high density strata along water sources during the dry spell and a dispersal after the rains (Allaway 1979, Leuthold 1977). In the study population, one such aggregation occurred in a riverine habitat (Zone 12) during the dry months. But in another river valley

(Zone 19), elephants, though present at a high density during the early dry period, began to disperse in March when water was even more difficult to obtain elsewhere. Obviously factors other than water influenced the movement of this clan. Elephants have to strike a compromise between food and water – both may not be necessarily available at their best in the same area.

A long-term perspective on elephant movement patterns

Sanderson (1878), who captured elephants in this area during the last century, made observations on their movement in the Biligirirangans which can be compared with the pattern today. The following lines are taken from his book:

> In the dry months – that is, from January to April, when no rain falls the herds seek the neighbourhood of considerable streams and shady forests. About June, after the first showers, they emerge to roam and feed on the young grass. By July or August this grass in hill tracts becomes long and coarse . . . elephants then descend now and again to the lower jungles, where the grass is not so far advanced . . . the herds invariably left heavy jungle about October for more open and dry country. About December, when the jungles become dry, and fodder is scarce, all the herds leave the low country, and are seldom seen out of the hills or heavy forests until the next rains.

The observations of Sanderson correspond exactly to the pattern observed for Clan 1 which ranges over Zones 3, 6, 7 and possibly adjoining areas. This was the region with which Sanderson was familiar. Obviously, the movement pattern of the elephants in this area has not basically changed for over a century. In this long-lived mammal, the adult females are repositories of traditional knowledge including migration routes. This could contribute to a conservative home range and movement pattern.

ACKNOWLEDGEMENTS

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Appendix I. Classification of habitat zones in the study area.

Zone number	Area km^2	Vegetation type	Trees/shrubs	Undergrowth grasses	Altitude (metres)	Topography
1	55	Dry deciduous	*Anogeissus latifolia* (Roxb.) Bedd., *Acacia sundra* D.C. Prod., *Lantana aculeata* L.	Short grasses	700–800	Flat
2	32	Dry deciduous	*Anogeissus*, *Terminalia* spp.	Tall grasses *Themeda triandra* Forsk	800–1000	Sloping westwards
3	125	Mixed deciduous	*Terminalia tomentosa* Wight & Arn, *Kydia calycina* Roxb., *Anogeissus*	Tall grasses *Themeda cymbaria* Hack.	1000–1400	Hilly
4	78	Evergreen *shola* forest and grassland	*Elaeocarpus*, *Meliosma microcarpa* Craib	Tall grasses *Cymbopogon* in the grassland	1400–1800	Hilly, steep
5	50	Dry deciduous	*Anogeissus*	Tall grasses, *Phoenix humilis* Royle	1000–1400	Sloping eastwards

Appendix I – *continued*

Zone number.	Area km²	Vegetation type	Trees/shrubs	Undergrowth grasses	Altitude (metres)	Topography
6	37	Dry deciduous	*Anogeissus, Phyllanthus emblica* L.	*Dendrocalamus strictus* Nees, tall grasses *Themeda triandra*	900–1000	Sloping, southwards and westwards aspects
7	60	Riparian fringing and deciduous	*Anogeissus, Zizyphus* spp.	Short grasses *Bambusa arundinacea* Ait. along stream	800–950	Flat, small hillocks
8	76	Dry deciduous	*Acacia* spp., *Zizyphus* spp.	Short grasses	900–1000	Undulating
9	21	Eucalyptus plantation	*Eucalyptus*	Short grasses	850–900	Flat
10	53	Dry deciduous woodland-scrub	*Anogeissus, Acacia* spp.	Short grasses	850–950	Flat
11	158	Dry deciduous, northern part (11A area 62 km²) more dry	*Anogeissus, Pterocarpus marsupium* Roxb.	*Phoenix humilis, Dendrocalamus,* tall grasses *Themeda* and *Cymbopogon*	950–1300	Hilly
12	27	Riparian fringing and deciduous	*Acacia* spp., *Lantana*	*Bambusa* along stream, short grasses and sedges	900–1000	Valley
13	28	Dry deciduous	*Anogeissus*	Tall grasses *Themeda* spp.	1000–1400	Hilly
14	32	Mixed deciduous	*Terminalia tomentosa, Kydia calycina*	Tall grasses *Themeda cymbaria*	1200–1350	Undulating valley
15	44	Dry deciduous	*Terminalia, Kydia, Anogeissus, Phyllanthus*	Tall grasses *Themeda* and *Cymbopogon*	1000–1300	Undulating
16	12	Grassland and eucalyptus plantation	*Eucalyptus*	Planted *Bambusa,* tall grasses *Cymbopogon*	900–1000	Undulating
17	136	Dry deciduous	*Anogeissus, Albizia* spp.	Tall and short grasses, *Themeda* spp.	400–1000	Steep slopes, southward aspect
18	44	Dry thorn	*Albizia amara* Boiv., *Acacia latronum* Willd.	Short grasses	250–400	Flat
19	62	Dry thorn and riparian	*Albizia amara, Acacia* spp., *Hardwickia binata* Roxb., *Gyrocarpus jacquini* Roxb.	Short grasses	250–400	Flat, valley

Appendix II. Estimation of seasonal elephant densities by ground transects.

Each zone was taken as the basic unit for sampling elephant density. Every trip into the field by vehicle or by walk was considered as a transect sample. Bias was largely minimized since the study area was divided into a number of habitat types for the purpose of sampling. The distance travelled, time spent and the number of elephants seen in each zone were recorded. For each zone the visibility for elephants was measured along the commonly used roads at intervals of 0.2 to 0.5 km so as to sample at least 30 locations. The average visibility for each zone was estimated at different seasons.

Ideally, if an observer were to transect an area as quickly as possible, the elephants recorded would be only those present at a given moment within the area visible. If the observer waits for some time, then more elephants could be expected to come into view. This 'flow' would be proportional to the time spent and the density of elephants. It has to be assumed that the average rate of movement of elephants is roughly the same in different zones since the observer has no control over this factor. Thus, the density of elephants calculated from transects involving a waiting period is likely to be greater than the real density. One solution to this problem would be to consider only those elephants seen while travelling and ignore those seen when the observer is stationary. But this would reduce sampling intensity in those zones where the distance travelled was short but in which the time spent was considerable. The problem lies in suitably incorporating the area scanned and the time spent into the model. Since area and time are separate dimensions it is not possible to easily relate one in terms of the other.

For the present study a relatively simple approach was taken. For one hilly habitat (Zone 11B) and one valley habitat (Zone 12) the records of elephant sightings during the two-month periods of highest sampling intensity were separated into two categories – those seen while the observer was in motion (distance travelled and area scanned is available) and those sighted when stationary (total time spent is available). The two-month periods were March–April 1981 for Zone 11B (258 km travelled, 32 hours spent) and March–April 1982 for Zone 12 (426 km travelled, 54 hours spent). From these it was calculated that the number of elephants seen for every 1 km^2 area scanned was the same as the number seen for about 3 hours (3.0 in Zone 11B and 2.8 in Zone 12) spent in waiting. Such a relationship was determined for only these two representative zones since the very high sampling effort and relatively high elephant density ensured the best possible estimates for the relationship. It has been assumed that this relationship also holds good for other zones. The formula used in calculating the seasonal density of elephants in different zones was

$$D = \frac{N}{A + (T/3)}$$

where D = density of elephants in km^2; N = total number of elephants seen; A = area scanned in km^2 (area = distance travelled × mean visibility); T = time spent in hours.

The estimates of elephant density are grouped into two-month classes for different zones. The results have been expressed at three levels of sampling intensity.

(a) High sampling effort. The area scanned exceeded 30% of the zone area, or over 100 km travelled or over 30 hours spent in a particular zone during a two-month period. The actual densities (indicated by asterisks) are given.

(b) Medium sampling effort. The area scanned exceeded 15% of the zone area, or over 50 km travelled or over 15 hours spent. The actual densities are given.

(c) Low sampling effort. Sampling intensities were below the medium level. Only the density ranges are given.

Zones		1981					1982						1983
No.	Area km^2	M–A	M–J	J–A	S–O	N–D	J–F	M–A	M–J	J–A	S–O	N–D	J–F
1	55	A	C	C	C	D	B	A	D	C	C	D	C
2	32	A	A	B	B	C	B	A	A	A	A	A	A
3	125	1.0	1.1	E	C	B	0.6	0.9	0.8	1.2	C	0.2	0.6
4	78	A	A	A	A	A	A	A	A	A	A	A	A
6	37	E	E	D	E	D	D	E	E	E	E	D	D
7	60	C	1.4	1.9	2.5	3.0	C	0.4	0.7*	E	E	E	B
9	21	A	<0.1	A	B	0.2	A	A	A	<0.1	B	C	A
10	53	B	B	B	D	D	B	B	B	D	D	D	D
11A	62	B	D	D	B	C	B	B	D	C	C	C	A
11B	96	1.3*	0.4*	0.2	0.1	0.7*	0.5*	0.2*	0.2*	0.1*	B	1.6*	1.6*
12	27	4.3*	0.8*	0.7*	0.8*	0.5*	5.0*	3.7*	0.6*	0.8*	D	0.3*	1.3*

Appendix II – *continued*

Zones		1981					1982						1983
No.	Area km²	M–A	M–J	J–A	S–O	N–D	J–F	M–A	M–J	J–A	S–O	N–D	J–F
13	28	C	A	A	C	B	C	B	A	A	C	B	A
16	12	1.3*	1.6*	C	0.8	1.7*	3.6*	0.4*	0.5	1.2*	E	2.0*	2.4*
17	136	<0.1*	<0.1*	<0.1*	A	<0.1	<0.1	<0.1	<0.1	<0.1	A	<0.1*	0.2*
18	44	B	<0.1	A	A	E	F	C	A	A	B	0.8	1.9
19	62	D	B	B	C	2.5	1.4	0.8	B	B	D	2.6	3.0*
Mean density		0.61	0.50	0.52	0.45	0.74	0.68	0.46	0.39	0.49	0.44	0.70	0.75
Number of elephants		564	463	483	420	691	628	424	364	452	412	654	699

The actual densities in elephants km^{-2} are given for instances of high sampling (indicated by *) and medium sampling efforts.

The density classes for low sampling effort are: A = <0.1, B = 0.1–0.25, C = 0.25–0.5, D = 0.5–1.0, E = 1.0–2.0, F = 2.0–4.0 elephants km^{-2}.