Population Estimation of Asian Elephants in a Tropical Forest of Northeast India

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Abstract. The long history of armed conflict in Manas National Park has resulted in the decline of wildlife populations. With the attainment of peace, knowledge of extant animal population sizes became crucial for making informed conservation decisions. The present study estimated the population of Asian elephants within a distance sampling framework using dung counts along 92 line transects. The population size was estimated to be 601 (95%, CI 454–797), with the highest density in mixed moist deciduous forest (1.57 elephants/km^2). This serves as the baseline information and also discusses the accuracy of the dung count method and possible shortcomings of our estimates.

Introduction

Assessment of large mammal population sizes becomes crucial for the management of protected areas (Waltert *et al*. 2008). Effective management practice can only be possible with a reliable estimate of population size and structure. The Asian elephant (*Elephas maximus*) is facing a severe threat to its survival from large-scale habitat loss and degradation, negative interaction between humans and elephants, and poaching across its range. The contiguous forests along the Himalayan foothills from northern West Bengal, eastward through Assam along southern Bhutan and Arunachal Pradesh, are considered to be vital for elephant conservation, with approximately 6000 elephants believed to range across the landscape (Santiapillai & Jackson 1990; Sukumar & Santiapillai 1996). The Manas National Park is a key protected area in the landscape and a primary habitat for elephants. Manas witnessed intense armed conflict from the mid-1980s to 2003, which resulted in habitat degradation, declining wildlife populations and smothering of conservation and management interventions (Goswami & Ganesh 2014). The social upheaval was put to halt with the formation of Bodoland Territorial Council (BTC) in 2003 and conservation actions were implemented. In the context of the armed conflict and resumption of conservation efforts, it was important that the elephant population in Manas be reliably estimated.

Traditionally, elephants have been censused in Manas with the help of the total count method conducted at five-year intervals. Although there is a lack of elephant population estimates from the park prior to 1980, it was believed that Manas still supported a good population of elephants, despite the turmoil. But it was important to corroborate this belief by obtaining a reliable estimate of elephant population size or density. Albeit the task of accurately estimating the elephant population in Manas is critical for implementing rational conservation measures, it is not an easy exercise and needed to be carried out with sufficient scientific rigour.

The line transect method involving distance sampling (Burnham *et al*. 1980) has been extensively used for estimating animal densities for a variety of taxa in various habitats (Karanth & Sunquist 1992; Varman & Sukumar 1995; Biswas & Sankar 2002; Jathanna *et al*. 2003; Wegge & Storass 2009; Wang 2010; Goswami & Ganesh 2014; Sinha *et al*. 2019). The direct count approach (i.e., counting the animal itself rather than its dung) is recommended in areas of good visibility and high elephant density (Jathanna

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et al. 2015). In areas of low elephant density, the indirect count method relying on elephant dung can be more feasible. Elephant densities have been estimated using line transect method either through direct counts (Karanth & Sunquist 1992; Jathanna *et al*. 2015) or indirect counts (Sale *et al*. 1990). The use of dung counts as a survey method to assess elephant populations, primarily those living in forest environments in low density, is well established (Barnes 1993, 1996; Barnes *et al*. 1997; Hedges & Lawson 2006). However, it is important to recognise that dung counts conducted along line transects under a distance sampling framework can accurately estimate the density of dung, but rely on two additional parameters to translate them to animal densities: dung decay rate and defecation rate. The variance in defecation and decay rates can have a strong influence on estimated animal density. Nevertheless, it is suggested that these variances, even when combined with the variance in dung density, can yield fairly modest variance in the final estimate of elephant density (Hedges & Lawson 2006). In Manas where dung piles are more readily detectable than elephants, the dung count method was more feasible to implement. To determine the elephant population numbers and density in different forest habitats of Manas National Park, detailed line transect surveys were conducted during 2009–2010. This study is the first effort to estimate elephant density and population size in Manas using a systematic line transect survey involving long-term monitoring of dung decay rates.

Methods

Study area

Our survey was conducted in three different administrative ranges of Manas National Park (26°35'–26°50' N, 90°45'–91°15' E) situated in the north-eastern state of Assam in India (Fig. 1). These ranges were namely Panbari Range (western), Bansbari Range (central) and Bhuyapara Range (eastern). These three ranges span both sides of the Manas River and are limited in the north by the international border of Bhutan, to the south by villages, and to the east and west by reserve forests. Altitude ranges from 50 m MSL on the southern boundary to 200 m MSL along the Bhutan hills (Sarma *et al*., 2008).

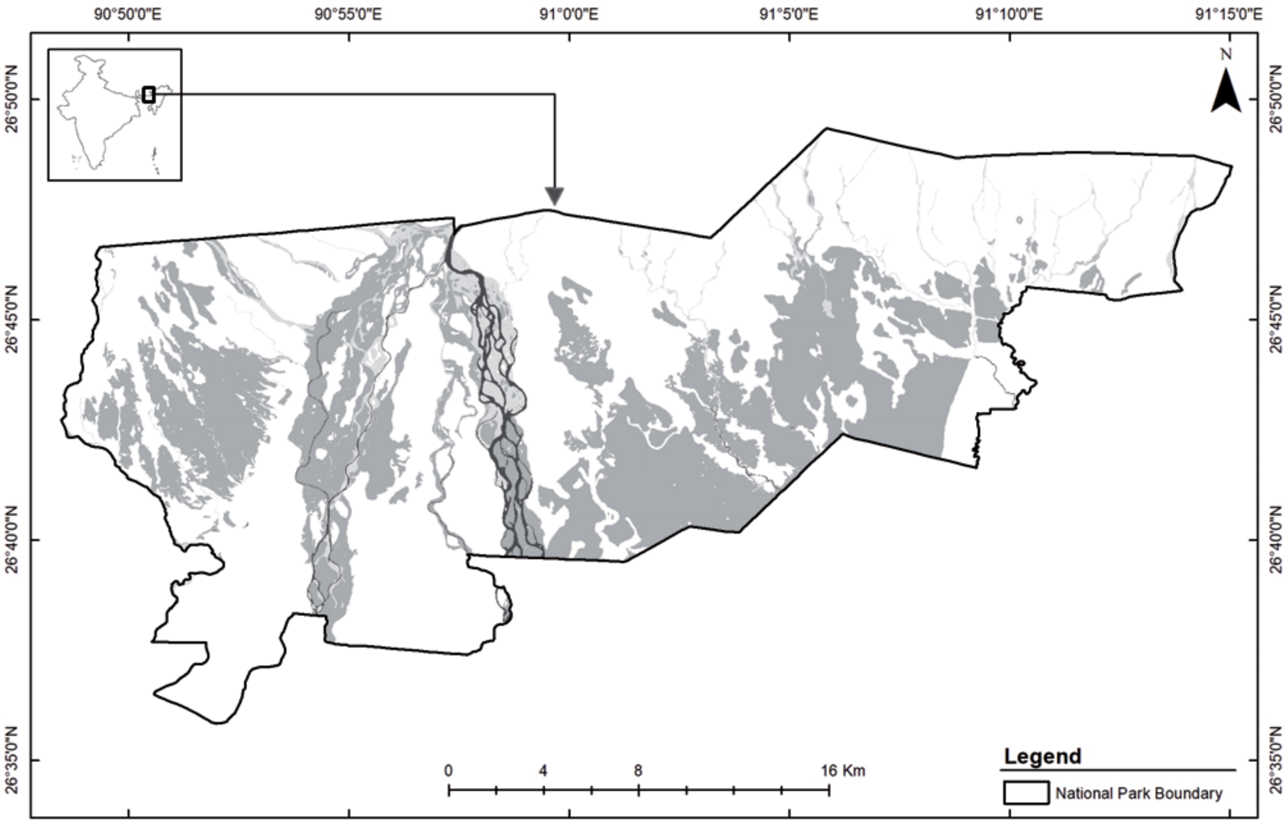

Figure 1. Map showing the location of Manas National Park in Assam. The grey areas represent the grasslands and the white areas represent woodlands. The dark waterbody is the river Beki.

The National Park occupies an area of 519 km^2 (Sarma *et al*. 2008), which forms the core area of the Manas Tiger Reserve (2837 km^2). There are three main types of vegetation: sub-Himalayan alluvial semi-evergreen forest, east-Himalayan mixed moist and dry deciduous forests and grasslands. Much of the riverine dry deciduous forest is an early successional stage, which is replaced by moist deciduous forest away from the water courses, and eventually succeeded by the semi-evergreen climax forests in the northern part of the Park.

The area under three different forest covers in Manas National Park is described in Table 1. based on Sarma *et al*. (2008).

Estimating elephant density using dung counts

The dung count method involving line transect surveys within a distance sampling framework requires a translation of dung density to elephant density. To achieve this, dung density needs to be calibrated by dung decay rates as well as defecation rates. Therefore, to estimate elephant numbers and density in Manas, the following data were collected in a stratified random manner: number of dung-piles encountered per km of transect walked, defecation rate of elephants, mean rate of dung decay; combining these three parameters, elephant numbers and density were estimated.

Table 1. Description of the three major habitats in Manas. The sampling was conducted in these three habitats.

Habitat type	Area (km^2)	Major plants
Semi ever-green	177.0	*Pterospermum acerifolium* *Dysoxylum binectariferum* *Phoebe goalparensis* *Amoora wallichi* *Sterospermum personatum* *Chukrassia tabularis* *Duabanga grandiflora* *Michelia champaca* *Linnea coromandelica* *Sterculia villosa*
Mixed moist deciduous	65.6	*Bombax ceiba* *Lagerstroemia flosreginae* *Careya arborea* *Terminalia bellerica* *Gmelina arborea*
Grasslands	206.5	*Narenga porphyrocoma* *Imperata cylindrica* *Phragmites karka* *Arundo donax* *Saccharum spontaneum* *Themeda arundinacea* *Saccharum procerum* *Vetiveria zizaanioides*
Total	449.1	

Number of dung piles per km

Habitat-based stratification was adopted to lay line transects ranging from 0.8 to 1.3 km across the study area. A total of 92 line transects, with a total length of 100.65 km were walked during the survey in two seasons: dry season (October – April) and wet season (May – September) (Table 2). All the transects had a random start location, with a fixed perpendicular orientation to roads and the major rivers of the park. Transects were oriented as such, to cut across the major drainage so as to maximise habitat representativeness of each transect (minimise probability of individual transects running entirely within or outside routes favoured by elephants).

All the transects were strictly maintained to be a straight line, and were spaced 2 km apart from each other. All transects were walked only once. Once on the transect, only those dung piles seen from the transect centre-line were recorded.

Estimation of defecation rate of elephants

Defecation rate/day is considered as one of the most important components in line transect surveys involving dung counts. However, the defecation rate may vary with habitat, season and individuals. Dung defecation rate of elephants depends on the elephant's diet, which in turn depends on the habitat type and the season (Dawson 1992). Obtaining data on defecation rates of wild elephants was not possible due to the difficulty of tracking elephants for long periods of time especially at night, which is potentially dangerous. This exercise can also be done by observing domestic animals if they

Table 2. Summary of number of transects (N) and their average, maximum and minimum surveyed lengths and effective strip widths (ESW).

Survey habitat	N	Transect length [km]				ESW [m]
		Average	Min	Max	Total	
Mixed moist deciduous forest	36	1.0	1.0	1.0	36.0	2.52
Semi evergreen forest	17	1.1	0.8	1.2	17.9	2.76
Grassland	39	1.2	0.9	1.3	46.8	2.66

are semi-wild and free ranging (Varma 2006). However, ecologists have a serious concern on this "borrowed defecation rate" as factors such as diet can play a major role in determining it.

Hedges and Lawson (2006) conducted a study in Way Kambas National Park in Sumatra (Indonesia) during 2000–2001 where they estimated an overall mean defecation of 18.07 times/day with 95% CI of 17.93–18.20 and a standard error of 0.0689. This estimate is considered as the standard estimate by 'Monitoring of Illegal Killing of Elephants', a CITES body in 2004. Hence, this defecation rate was used in our study in the absence of location specific data.

Estimation of mean rate of dung decay

The rate of dung decay depends on a combination of several factors that include the action of dung beetles, exposure to climatic factors and composition of the dung itself (Alfred *et al*. 2010). To estimate the rate of dung decay in the study area, 41 fresh dung piles were marked in forests of three different vegetation types following Laing *et al*. (2003), including: (i) semi evergreen forest (forest canopy ranged between 80–100%, which normally represents undisturbed forest); (ii) mixed moist deciduous forest (forest canopy ranged between 40–80%, which normally represents secondary forest); and (iii) grasslands (forest canopy ranged between 0–30%, which represents treeless areas).

The dung decay observations were carried out between September 2009 and November 2010, simultaneously with the transect surveys. Each fresh marked dung pile was relocated using the GPS and compass, and its state of decay was recorded at an interval of every 15 days.

Dung decay rates observed were 74.46 days in mixed moist deciduous forest, 98.44 days in semi evergreen forest and 89.52 days in grasslands. Differences in decay rates among the three habitats were not significant (Kruskal-Wallis test: $K = 4.01$, $df = 2$). Hence, we combined the decay rate data for the different habitats under dry and wet season categories. Out of the 41 dung piles, 25 fresh dung piles were marked in the dry season and 16 in the wet season. We found no significant difference in the mean decay rate of dung-piles between the seasons (Independent t-test: $t = 0.49$, $df = 39$, $p = 0.98$). Therefore, the data were pooled and used to calculate the mean number of days for decay, which was estimated as 86.7 ± 8.19 ($n = 41$) (Table 3).

Estimation of elephant density

We used the program DISTANCE v6.2 to analyse the data, which allows the selection of different models and also includes a range of different options (Burnham *et al*. 1980). In the software, we first included the dung count data (the perpendicular distance from the observer), defecation rate and decay rate. The probability of detection was estimated using six models recommended by Buckland *et al*. (2001) combining probability density function (uniform, half normal and hazard-rate) with adjustments (cosines, simple and hermite polynomials). The model with the lowest Akaike's Information Criterion (AIC) was selected for each sampling zone unit. The program automatically calculates

Table 3. Decay rate [days] of dung piles in three different habitat types irrespective of seasons.

Habitat	N	Mean	SE
Grassland	17	89.52	13.29
MMD	15	74.46	13.42
Semi evergreen	9	98.44	19.87

the F(0) from the perpendicular distance data. This is an estimate of the reciprocal of the 'Effective Strip Width' (ESW).

The density of dung-piles (D) is then calculated by the following formula:

D = n x F(0) / 2L

Where:

n = number of dung piles

L = total length of the transects in which they were recorded

Variance of D and the confidence limits are estimated following Burnham *et al*. (1980). F(0) is the probability density function of detected distances from the line, evaluated at zero distances (Alfred *et al*. 2010). Further, dung density (D) was estimated for each habitat type and the population size (N) was computed based on the size of the habitat area. Often an encounter rate (n/L) is computed as an index for sample size considerations or even as a crude relative density index (Alfred *et al*. 2010).

The data were stratified based on habitat types to detect separate detection functions for each habitat and the global density was estimated by using the mean of each habitat weighted by the habitat area. We ran the program with various combinations of the key and adjustment functions that provide flexibility in modelling the detection function g(x). The models recommended in this computation are likely to perform reasonably well, since the AIC generated by each model is used as a selection guideline. The model that generated the lowest AIC is considered as a reasonable density. In the trial analysis, the model fit was poor based on goodness-of-fit tests, due to observations far from the line and

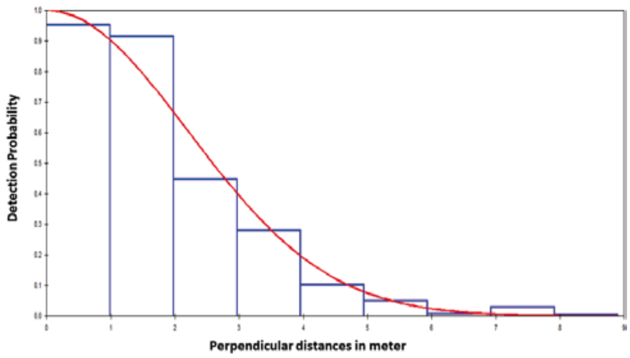

Figure 2. A typical visibility curve of recorded dung piles with no data truncation.

some significant outliers. Hence, the data were truncated at the distance where g(x) = 0.15 and analysed further after truncation.

Results

A total of 1068 dung-piles were recorded in 92 line transects. No dung-piles were recorded beyond a distance of 8 m from the centre-line of the transects (Fig. 2). The density estimates in six different models, as recommended by Buckland *et al*. (2001) are summarised in Table 4. Hazard rate function with cosine adjustment term was selected as the best model based on the lowest AIC value. The estimated overall density of elephants was found to be 1.33 km^2 (CV 14.22%, 95% CI: 1.01–1.77). However, different densities of elephants were found to occur in the three different habitats (Table 5). The population of elephants in Manas National Park was estimated as 601 (CV: 14.22 %, 95% CI: 454–797).

The grasslands had the highest estimated number of elephants with a population of 269 ± 39 (95% CI: 201–358), followed by semi evergreen forest with a population of 230 ± 48 (95 % CI: 151–349). The lowest estimate was in the mixed moist

Table. 4. Summary of the global density of elephants per km^2 in all six models recommended by Buckland *et al*. (2001).

Model	Density	CV %	Upper CL	Lower CL	AIC
Uniform + cosine	1.36	14.09	1.80	1.03	3481.0
Uniform + simple polynomial	1.23	14.14	1.63	0.93	3510.1
Half normal + cosine	1.40	14.23	1.86	1.05	3471.9
Half normal + hermite polynomial	1.28	14.17	1.70	0.97	3523.2
Hazard rate + cosine	1.33	14.22	1.77	1.01	3470.6
Hazard rate + simple polynomial	1.28	14.37	1.70	0.96	3478.5

Table 5. Density and population estimates in three habitats.

Habitat type	Density parameter (elephants/km^2)			Number parameter (# elephants)		
	Point estimate	SE	% Coef. of Variation	Point estimate	SE	95% CI
Mixed moist deciduous	1.57	0.25	15.97	103	16.45	75–142
Semi evergreen forest	1.29	0.27	20.82	230	47.88	151–349
Grassland	1.30	0.18	14.53	269	39.07	201–358

deciduous type of forests with a population of 103 ± 16 (95% CI: 75–142). However, in terms of elephant density, the mixed moist deciduous forest had the highest density of elephants with 1.57 ± 0.25 individuals per km^2 (95 % CI: 1.14–2.15) followed by grasslands with 1.30 ± 0.18 individuals per km^2 (95 % CI: 0.97–1.73). The lowest density was estimated in the semi evergreen forests (1.29 ± 0.27 individuals per km^2 (95% CI: 0.85–1.97).

Discussion

Estimation of mean rate of dung decay

Dung decay rates can be highly site specific (Hedges & Lawson 2006). Factors like the diet of elephants, vegetation cover, prevailing weather conditions and rainfall patterns may influence the decay rate of a fresh dung pile. The presence of ground feeding birds such as jungle fowl, partridges, and quail can also accelerate the deterioration rate of elephant dung piles (Wanghongsa & Boonkird 2004).

Though the dung decay rates were different in the three habitat types, they were not significant. Moreover, there was no seasonal difference in dung decay rate during the study period unlike that observed in some other studies (e.g., Wanghongsa & Boonkird 2004). The effect of the weather on decay rate thus seemed to have a minimal effect in our case. In contrast, Wanghongsa and Boonkird (2004) found that weather conditions had a significant effect on dung decay rates, with dung piles decaying 2.14 times faster in the wet season. This is probably due to the high activity of insects in the wet season (Alfred *et al*. 2010). Wanghongsa and Boonkird (2004) recorded about 29 families of insects to have influenced dung pile decay from 100 dung piles.

Figure 3. Elephant herd visiting the Burhaburi camp in Manas. Photo by Abhijit Boruah.

Estimates of elephant population

The population estimate of the present study (601 elephants, 1.33 elephants/km^2) is not comparable with an earlier estimate of the department (780 elephants, 1.68 elephants/km^2) obtained in 2008 (Census Report 2009) because different sampling methods were used. Although there is reluctance to use the dung count method to estimate elephant population size, available evidence indicates that it can give good estimates with reasonable confidence limits (Jachmann 1991; Barnes 2001, 2002; Eggert *et al*. 2003). The dung count method is used extensively for estimating elephant numbers in forested areas, yet there is considerable scepticism concerning its accuracy (Barnes 2001). Published accounts of dung counts show that they give estimates similar to those from other methods for vertebrates ranging in size from lizards to elephants (Todd *et al*. 2008). Thus, dung counts are as accurate or inaccurate as other methods for estimating vertebrate numbers including elephants (Barnes 2001).

Detectability plays a key role in estimating dung densities and ignoring this may lead to erroneous outcomes in estimating the population size. Different habitat types may have different detection probability and in the present study, the detection probability in the three habitats varied from 0.40 in mixed moist deciduous forests and 0.43 in grasslands to 0.50 in semi evergreen forests. In absolute terms, these estimates of detection probability suggest that nearly half of the elephant population could be missed during surveys in Manas, irrespective of habitat type, if detection probability was not accounted for. In addition, there could be habitat-specific variation in detection probability, as evident in this study, because of differences in vegetation types and thickness of the forest. The grasslands in Manas tend to be thicker and denser during peak monsoon and post monsoon, which limits visibility and thereby detection probability to a great extent. Inaccessibility in a large habitat like Manas may also limit sampling intensity. The difficulty of travel and observation in forests sometimes means that the amount of data that can be collected per unit effort is low (Walsh *et al*. 2001). The dung count method is considered to be more cost effective than the more sophisticated dung DNA method (Hedges *et al*. 2013). Considering all these factors, we applied the line-transect based dung count method to elephant population estimation, which is well suited to the prevailing vegetation in Manas.

We found that the density of elephants was highest in mixed moist deciduous forests than in the other two habitats during the study period. This can be due to availability of more diverse forage in mixed moist forests than in reasonably homogenous grasslands. Some of the fodder plants, including *Dillenia indica*, were observed more in the mixed moist forests, which may attract elephants. While examining dung piles, *Dillenia* fruit parts were recorded to a great extent. Sukumar *et al*. (2003) recorded the same from Buxa Tiger Reserve.

Besides, the Forest Department's population census data, there are no other empirical data on elephant population size and density in Manas to compare with. Historical estimates are doubtful and mainly educated guesses. Therefore, this result provides a new baseline for population size with scientific methods. The population in Manas has always drawn attention because of its international importance as a park. Since it is part of a transboundary landscape the park is significantly utilized by migrating elephants during both seasons. This 'open' population gains added importance as it is likely to contribute to maintaining better genetic diversity across the larger landscape. The increased human–elephant conflict in the fringe areas of the park (Nath *et al*. 2009) and considerable change in the land-cover types in the study area (Sarma *et al*. 2008) lead to potential threats to the long-term existence of elephants in the region. The larger landscape of the Ripu Chirang Elephant Reserve, of which the Manas National Park is a part, has witnessed extensive deforestation during the last decade or so. This has led to fragmentation of the otherwise contiguous forested landscape that facilitates the movement of elephants across the region. This deforestation has caused loss of prime habitats mostly in parts of Kachugaon and Holtugaon forest divisions. Unfragmented habitat is essential for long-term conservation of Asian elephants, as the species depends on entire landscapes rather than a few habitat patches (Leimgruber *et al*. 2003). The study shows that for populations such as the one in Manas, estimates from the low-cost dung count method are feasible to obtain and have scientific validity.

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