
Statistical Techniques for Estimating the Abundance of Asiatic Elephants Based on Dung Piles

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Abstract

In this chapter we presented the field methods and statistical models used for estimating elephant density and elephant population for different Elephant Reserves of Kerala. The Elephant Census was organized in the four Elephant Reserves of Kerala State during 2005 and 2007 by the Kerala State Forest and Wildlife Department.

Keywords

Line transect sampling · Dung decay rate · Dung defecation rate · Kerala · Western Ghats

19.1 Introduction

Information on elephant population in forests is essential for its effective management. Different methods have been used for the direct survey of elephants like total count, sample count, water hole count, and line transect sampling – direct sighting. These direct methods are usually more prone to sample error due to scattered occurrence of elephants, group behavior, and its vast home range (Jachmann 1991).

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Further, direct sighting of elephants over vast area is practically problematic. However, elephants leave indirect evidence such as dung, which continues to be present in the area for a considerable time period. The estimation of elephant population through surveys of dung is practically an easy method and becoming popular.

Standing crop method and clearance plot method are the possible indirect methods for estimating elephant population. The standing crop method is based on the assumption that there is a stable relationship between the amount of dung present and the number of animals. This method requires one-time survey of dung, and dung count is corrected by defecation and decay rate. The clearance plot method involves clearing dung from marked plots at regular intervals, counting the droppings, and correcting the counts by the defecation rate (Staines and Ratcliffe 1987). Most of the studies in tropics fall under the framework of standing crop method. In order to convert the dung density into elephant density (number of elephants per unit area), the following formula is usually adopted:

$$\text{Estimated density of elephants, } \hat{D}_e = \frac{\text{Dung density}}{\text{Defecation rate}} \times \text{Dung decay rate}$$

Dung density (number of dung per unit area) is usually estimated through surveys of dung using quadrat sampling, strip transects sampling, or line transect sampling. Line transect sampling was followed in this study. Defecation rate (number of dung defecated per day per animal) can be estimated by monitoring captive elephants or by placing a known number of elephants in an enclosure previously cleared off dung and estimating the number of dung produced over a fixed time period. The dung decay rate is defined as the number of dung decayed per day and is expressed as the reciprocal of the estimated mean time to decay (Barnes and Barnes 1992).

Dung decay rate can be estimated by conducting experiments in which the fresh dung piles are located and marked and monitored over a period of time until they disappear. Most of the studies use decay rate for estimating elephant population with the assumption that the system is in a steady state throughout the period of decay experiments. The steady-state assumption states that the number of dung piles being deposited each day equals the number of dung piles disappeared each day, i.e., the number of dung piles per unit area remains constant from day to day (Barnes and Jenson 1987; Barnes and Barnes 1992). Further, dung decay rate has been estimated assuming an exponential rate of decay independent of age or by curve fitting over age-specific mortality of dung piles. However, these estimations have been found confounded with steady-state assumption and biases such as seasonal variation in decay rates. It is also seen that the decay rate (as well as defecation rate) is borrowed from other studies conducted in similar areas or even from distant places for the estimation of elephant population (Easa et al. 2002).

Laing et al. (2003) provided a robust methodology for estimating mean time to decay, which they termed it as “retrospective estimate” of the mean time to decay. In this method, fresh signs of the animal are located and marked on several dates in

the lead-up to the survey, chosen so that the proportion of signs surviving from the earliest date to the survey is expected to be small, and to return to marked signs just once, at the time of the survey. Data on status of the signs are then binary, recording whether or not the signs survive to the date of the survey. This binary data are subjected to the logistic regression analysis, and mean time to decay is estimated. In this chapter, the dung survey methods and statistical models employed for the population estimation of wild elephants in the forests of Kerala State are presented.

19.2 Survey Methods

19.2.1 Organization of the Census Program

The Elephant Census was organized in the four Elephant Reserves of Kerala State under the direction and guidance of the Chief Conservator of Forests (Wildlife) (Fig. 19.1). The Field Director of the Periyar Tiger Reserve was the State Coordinator of the census. The Conservators of the Wildlife Wing were nominated as the Coordinators of the respective Regions. The actual census was carried out on 2 days. In the year 2005, the block count method was carried out on 5 May 2005 and dung survey using line transects sampling on 6 May 2005 (Sivaram et al. 2005). In the year 2007, the block count method was carried out on 7 May 2007 and dung survey using line transects sampling on 9 May 2007 (Sivaram et al. 2007).

A 1-day training program was organized for the selected forest officers (resource persons) at different places. The officials in the meeting were briefed on the field techniques to be followed in the census, the method of filling the proforma and also on the care to be taken while collecting the data. The doubts of the resource persons were cleared during the discussions that followed. The method of census and the procedures to be followed in the field for the success of the program were explained to the field staff in detail in the regional meetings of the forest officers convened by the respective coordinators.

The toposheets of the forest areas were taken to the Divisional Forest Offices/Ranges, and the blocks were demarcated by the Forest Range Officers and the field staff. The copies of such maps were sent to the Divisional Forest Offices with instructions on laying transects in the selected sample blocks. Transects were laid by the forest officers in the selected blocks and marked with paint/colored biodegradable ribbons.

A proforma for the census was prepared and got printed along with the instructions to the participants. The materials such as field compass, measuring tapes, notebooks, and pencils were procured. The required number of kits containing these materials and the proforma were distributed to the offices of the Conservators. The Forest Range Officers later collected these items.

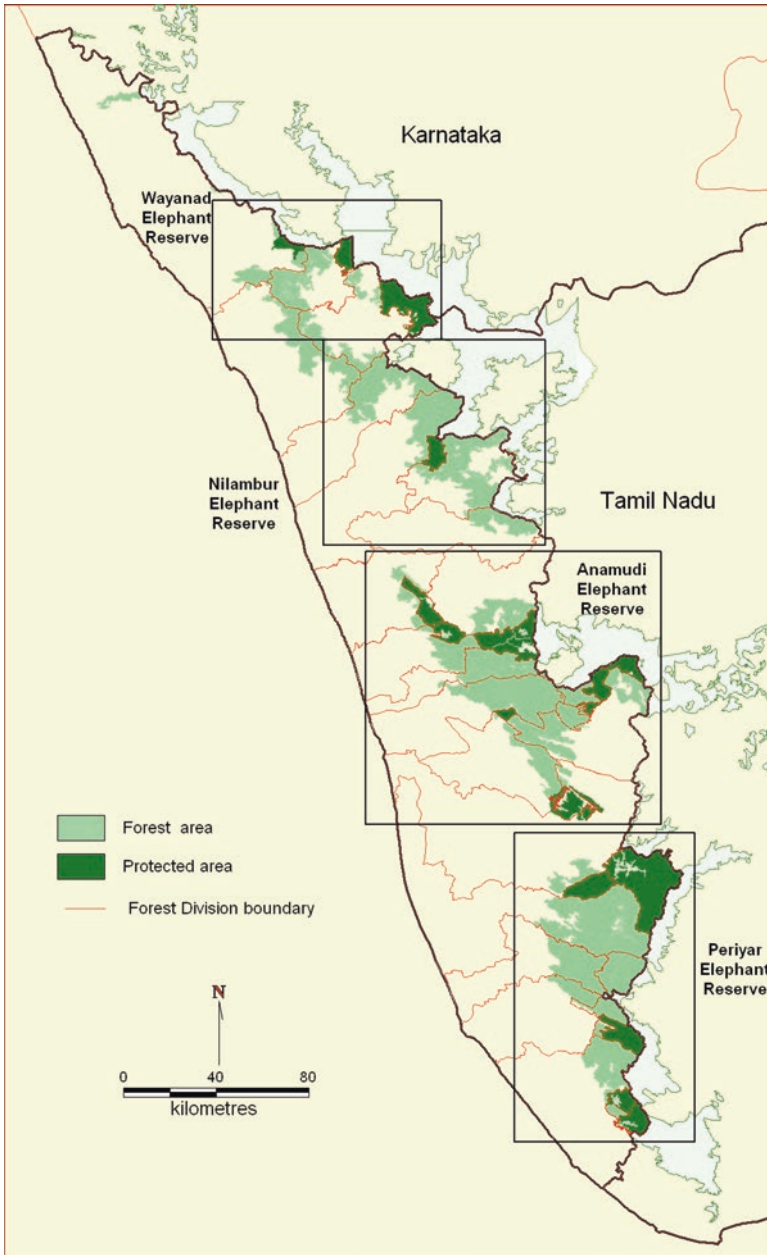


Fig. 19.1 Elephant Reserves of Kerala

Table 19.1 Total area of sampled blocks and number of blocks sampled

Elephant reserve	Number of blocks sampled		Total area of sampled blocks (km ²)	
	2005	2007	2005	2007
Wayanad ER	74	82	501.75	584.71
Nilambur ER	89	93	576.50	884.09
Anamudi ER	188	195	1163.69	1324.77
Periyar ER	166	213	1359.22	1862.02
Total	517	583	3601.16	4655.59

19.2.2 Sampling of Blocks

The total forest area of each Protected Area/Territorial Forest Division was divided into number of small blocks utilizing the Survey of India maps. A random sample of blocks was chosen in each Protected Area/Territorial Forest Division for the enumeration. The total number of blocks sampled was 517 in the year 2005 and 583 in the year 2007. The details of the total number of blocks sampled and area sampled in each Elephant Reserve are given in Table 19.1.

19.2.3 Line Transect Sampling: Elephant Dung Survey

19.2.3.1 Line Transect Sampling

Line transect sampling is one of the widely used scientific methods (Buckland et al. 2001). If the method is applied properly, it provides a viable technique to determine point estimates and measures of variance of animal density (in the present context dung density). In line transect sampling, the observer(s) perform a standardized survey along a series of lines, searching for objects of interest such as cluster of animals and dung piles. For each object detected, they record the perpendicular distance from the line to the object or radial distance from the observer to the object along with the angle of sighting. The main advantage with line transect sampling is that even without encountering all the objects of interest in the area, it is possible to develop an estimate of the total number of objects or their density through appropriate statistical analyses. However, the method presupposes adequate sample size in terms of sightings without which precise estimate of density cannot be obtained by this method. Burnham et al. (1980) recommend a minimum of 40 sightings of objects of interest for satisfactory estimation of the detection function in the area.

19.2.4 Line Transect Sampling: Elephant Dung Survey

The technique of line transect sampling was adopted in all the sampled blocks. In each sample block, transect of about 2 km length was laid by marking trees with paint or colored biodegradable ribbons. These transects were covered on foot

Table 19.2 Details of line transects laid in different Elephant Reserves of Kerala during the year 2005 and 2007

Elephant reserve	Total number of transects		Total length of transect (km)		Total number of dung piles recorded	
	2005	2007	2005	2007	2005	2007
Wayanad ER	75	82	148.0	163.15	1434	3557
Nilambur ER	88	93	179.8	183.01	718	1353
Anamudi ER	173	195	363.6	388.92	3286	4615
Periyar ER	166	214	331.8	420.95	1908	3528
Total	502	584	1023.2	1156.03	7346	13,053

recording the perpendicular distance to the geometric center of the elephant dung piles. The perpendicular distance was measured using a tape. The details of the number of transects sampled in each Elephant Reserve are given in Table 19.2.

19.2.5 Elephant Dung Decay Experiments

The dung decay experiments were conducted on a sample of fresh dung piles in all the four Elephant Reserves of Kerala representing different vegetation types following the retrospective method suggested in Laing et al. (2003). A number of field visits were made, adding fresh dung piles to the sample and also recording the state of the dung piles previously marked. A fresh dung pile is the one, which is 0–24 h old. The state of the dung pile was recorded as present (= 1) or absent (= 0) indicating the decay status of the dung piles. Present is defined as any stage where some dung material is still left. Absent is a stage where only traces (e.g., plant fiber remains, termite mounds, mud, etc.) are left and no dung material is present. Absent also includes “total disappearance” of dung pile (e.g., washing away in heavy rains).

Each dung pile was marked and numbered uniquely using one of the following methods.

1. During each visit, the previously marked dung piles were visited and their status noted.
2. If, however, a marker was missing and the marked dung pile could not be located accurately, it was excluded from the sample and fresh dung piles were marked during that visit.
3. During the last visit, the status (Presence/Absence) of all previously marked dung piles was noted. No fresh dung pile was marked on this visit.

The experiment was initiated about 105 days before the actual census. The field visits were made every fortnight as per the schedule prepared for each Forest Range, searching for fresh elephant dung in each vegetation type and marking the same for assessing its future status (present/absent). The details of the experiments were recorded using an observation form.

19.3 Statistical Models

19.3.1 Extent of Actual Elephant Habitat

Extent of actual elephant habitat is a crucial multiplication factor in extrapolating elephant population. Therefore, efforts were made to arrive at the actual extent of elephant habitat by consulting government notifications, published reports, and forest working plans. Apart from the forest areas, which are definitely devoid of elephants such as Thrissur Forest Division and Kumily Forest Range, the blocks that are devoid of elephants in various Forest Divisions, water bodies, and other enclosures were accounted for and the actual elephant habitat worked out. The details of the area devoid of elephant and the actual elephant habitat for various Elephant Reserves are presented in Table 19.3.

19.3.2 Line Transect Sampling: Dung Survey

In strip sampling, if strips of width 2ω and total length L are surveyed, an area of size $a = 2\omega L$ is censused. All n objects within the strips are enumerated, and estimated density is the number of objects (in our case dung piles) per unit area:

$$\hat{D} = \frac{n}{2\omega L}$$

In line transect sampling, only a proportion of the objects (dung piles) in the area a surveyed is detected. Let this unknown proportion be P_a . If P_a can be estimated from the distance data, then we would estimate density by

$$\hat{D} = \frac{n}{2\omega L \hat{P}_a}$$

Table 19.3 Details of area devoid of elephant and actual area used for extrapolating elephant population in different Elephant Reserves of Kerala

Elephant reserve	Forest area (km ²)	Effective forest area (km ²) ^a	Area devoid of elephants (km ²)	Actual area used for extrapolating elephant population (km ²)
Wayanad ER	1200	1101.05	166.89	934.16
Nilambur ER	1419	1255.71	113.41	1142.30
Anamudi ER	3728	3365.92	548.47	2817.45
Periyar ER	3742	3411.73	385.32	3026.41
Total	10,089	9134.41	1214.09	7920.32

^aEffective forest area was computed for different Elephant Reserves by allocating the total effective forest area of the state (9400 km²) in proportion to the total forest area of territorial forest divisions falling under the respective Elephant Reserve

where the unconditional probability of detecting an object in the strip is

$$P_a = \frac{\int_0^{\omega} g(x) dx}{\omega}.$$

Substituting the estimator of P_a into \hat{D} gives

$$\hat{D} = \frac{n}{2L \int_0^{\omega} \hat{g}(x) dx}.$$

The probability density function of the perpendicular distance data, conditional on the object being detected is

$$f(x) = \frac{g(x)}{\int_0^{\omega} g(x) dx}.$$

By assumption $g(0)$, the probability of detection on the line is 1, so that the pdf, evaluated at zero distance, is

$$f(0) = \frac{1}{\int_0^{\omega} g(x) dx}.$$

Therefore, the general estimator of density for line transect sampling is

$$\hat{D} = \frac{n\hat{f}(0)}{2L}. \quad (19.1)$$

The formula for $var(\hat{D})$ is given in Buckland et al. (2001). Some generally useful models of $g(x)$ are given in Table 19.4. The series expansion added in the model is used to adjust the key function, using one or two more parameters, to improve the fit of the model to the distance data.

The perpendicular distances to dung piles formed the input data for the estimation of dung density. The density estimates were obtained using the formula (19.1) above. Univariate half normal distribution with the series expansion of simple polynomial/hermite polynomial was used as detection function for estimating the dung density. A 5% truncation of the largest perpendicular distance values was adopted to improve the precision of the density estimates. The software DISTANCE 5.0 Release 2 developed by Thomas et al. (2006) was used for all calculations. The dung density estimates were worked out at the habitat level and Elephant Reserve level by pooling the data appropriately.

19.3.3 Measuring Dung Decay Rate

19.3.3.1 Choice of Statistical Technique

Dung decay rate is the reciprocal of the average survival time of the dung piles. The average survival time is estimated by fitting appropriate mathematical model

Table 19.4 Models of the detection function used in line transect sampling

Key functions	Series expansion
Uniform, $1/\omega$	Cosine, $\sum_m^{j=1} a_j \cos(j\pi x / \omega)$
Uniform, $1/\omega$	Simple polynomial, $\sum_m^{j=1} a_j (x / \omega)^{2j}$
Half-normal, $\exp(-x^2/2\sigma^2)$	Cosine, $\sum_m^{j=2} a_j \cos(j\pi x / \omega)$
Half-normal, $\exp(-x^2/2\sigma^2)$	Hermit polynomial, $\sum_m^{j=2} a_j H_{2j}(x_s)$, where $x_s = x/\sigma$
Hazard-rate, $1 - \exp(-(x/\sigma)^{-b})$	Cosine, $\sum_m^{j=2} a_j \cos(j\pi x / \omega)$
Hazard-rate, $1 - \exp(-(x/\sigma)^{-b})$	Simple polynomial, $\sum_m^{j=1} a_j (x / \omega)^{2j}$

relating survival status of the dung piles with the age of the dung piles (i.e., duration of the dung piles up to which the dung piles survived). It was attempted to subject the data collected from dung decay experiments conducted in different Elephant Reserves to logistic regression model following Laing et al. (2003). However, it was observed from detailed analysis that the data collected from different Elephant Reserves were not found to follow the logistic regression model. Further, to apply logistic regression model, it was suggested that 90% of the indirect evidences followed up should be decayed by the end of the experiment (i.e., by the end of 105 days). In the dung decay experiments conducted in Kerala for the present elephant population estimation, such a situation was not seen. In Wayanad Elephant Reserve, a large number of dung piles were surviving even after 105 days. In other Elephant Reserves, most of the dung piles decayed well before 105 days (Sivaram et al. 2005). So, we had to resort to alternative statistical technique for analysis. We used Kaplan-Meier survivorship function (Hosmer and Lemeshow 1999) for estimating average survival time of the dung piles (referred to as time to decay).

19.3.3.2 Kaplan-Meier Survival Analysis

In studying the survival time of the dung piles using a follow-up study for a specified period of time, the primary outcome variable concerned is the number of days that the respective dung piles will survive. At the end of the study, it may be found that there will be dung piles that survived over the whole study time even if they have entered late and other dung piles that failed to follow up. The follow-up time is different for each dung piles as the entering time for each dung piles is different. The dung piles that failed to follow up may be ignored considering as missing data (since most of them are “survivors”). These dung piles, however, contain partial information on the

survival time. Such observations are called censored observations. The censored observations include dung piles still alive at the end of study or dung piles lost to follow up or left study before the end or event not recorded properly. The Kaplan-Meier estimator of the survivorship function is free of models (nonparametric) and incorporates information from all of the observations available, both uncensored and censored, by considering survival to any point in time as a series of steps defined by the observed survival and censored times. This estimator is a product of a number of conditional probabilities resulting in an estimated survival function $S(t)$ in the form of a step function. This estimator is also called as the product limit estimator.

The following is the general formulation of Kaplan-Meier estimator (Hosmer and Lemeshow 1999). Assume that we have a sample of n independent observations on dung piles denoted $(t_{(i)}, c_{(i)})$, $i = 1, 2, \dots, n$ of the underlying survival time variable T and the censoring indicator variable C . Assume that among the n observations, there are $m \leq n$ recorded times of absence of dung pile. We denote the rank-ordered survival times as $t_{(1)} < t_{(2)} < \dots < t_{(m)}$. Let the number of dung piles at risk of decaying at $t_{(i)}$ be denoted n_i , and the observed number of dung piles decayed be denoted d_i . The Kaplan-Meier estimator of the survivorship function at time t is obtained from the equation

$$\hat{S}(t) = \prod_{t_{(i)} \leq t} \frac{n_i - d_i}{n_i}$$

with the convention that

$$\hat{S}(t) = 1 \text{ if } t < t_{(1)}.$$

Using delta method, variance of the survivorship function is obtained as

$$\widehat{\text{Var}}\left(S(t)\right) = \left(\hat{S}(t)\right)^2 \sum_{t_{(i)} < t} \frac{d_i}{n_i(n_i - d_i)}.$$

In the analysis of survival time, the sample mean is not as important a measure of central tendency as in other settings due to the fact that censored survival time data are most often skewed to the right. The use of median time is the best option in such cases. The median survival time was used to work out the decay rate.

Median time is the second quartile (50th percentile), denoted by \hat{t}_{50} . The interpretation of this value is that we estimate that 50% will survive at least up to the time point \hat{t}_{50} .

$\hat{t}_{50} = \min\left\{t : \hat{S}(t) \leq 0.50\right\}$. In general, the estimate of the p th percentile is

$\hat{t}_p = \min\left\{t : \hat{S}(t) \leq (p/100)\right\}$. The estimator for the variance of the estimator of the p th percentile is

$$\widehat{\text{Var}}\left(\widehat{t}_p\right) = \frac{\widehat{\text{Var}}\left(\widehat{S}\left(\widehat{t}_p\right)\right)}{\left[\widehat{f}\left(\widehat{t}_p\right)\right]^2}$$

where
$$\widehat{f}\left(\widehat{t}_p\right) = \frac{\widehat{S}\left(\widehat{u}_p\right) - \widehat{S}\left(\widehat{l}_p\right)}{\widehat{l}_p - \widehat{u}_p}.$$

The values \widehat{u}_p and \widehat{l}_p are chosen such that $\widehat{u}_p < \widehat{t}_p < \widehat{l}_p$ and are obtained from the equations shown below.

$$\widehat{u}_p = \max\left\{t : \widehat{S}(t) \geq (p/100) + 0.05\right\}$$

and
$$\widehat{l}_p = \min\left\{t : \widehat{S}(t) \leq (p/100) - 0.05\right\}.$$

The end points of 100(1- α) percent confidence interval of \widehat{t}_p are

$$\widehat{t}_p \pm z_{1-\alpha/2} \widehat{\text{SE}}\left(\widehat{t}_p\right)$$

where
$$\widehat{\text{SE}}\left(\widehat{t}_p\right) = \sqrt{\widehat{\text{Var}}\left(\widehat{t}_p\right)}.$$

The assumptions to be made in using Kaplan-Meier estimator are:

- Censored individuals have the same prospect of survival as those, which continue to be followed. This cannot be tested for and can lead to a bias that artificially reduces $S(t)$.
- Survival prospects are the same for early as for late recruits to the study (can be tested for).
- The event studied (e.g., disappearance of dung) happens at the specified time. Late recording of the event studied will cause artificial inflation of $S(t)$.

19.3.3.3 Log-Rank Test

Log-rank function provides methods for comparing two or more survival curves where some of the observations may be censored and where the overall grouping may be stratified. The methods are nonparametric in the sense that they do not make assumptions about the nature or shape of the underlying distributions of survival estimates. The null hypothesis tested is that the risk of death/event is the same in all groups. In the case of absence of censorship, log-rank test reduces to Mann-Whitney

test for two groups of survival times and Kruskal-Wallis test for more than two groups of survival times. The mathematical formulation for log-rank test for l factor levels to be compared over s stratum levels is as follows (Hosmer and Lemeshow 1999; SPSS 2006).

Let $n^{(s)}$ be the number of subjects in stratum s . Let $t_1^{(s)} < \dots < t_{m_s}^{(s)}$ be the observed failure times (responses) and

$n_{li}^{(s)}$ = the number of individuals in group l at risk just prior to $t_i^{(s)}$ in stratum s

$d_{li}^{(s)}$ = number of deaths $t_i^{(s)}$ in group l

and

$$d_i^{(s)} = \sum_g^{l=1} d_{li}^{(s)}$$

$$n_i^{(s)} = \sum_g^{l=1} n_{li}^{(s)}.$$

Hence, the expected number of events in group l at time $t_i^{(s)}$ is given by

$$E_{li}^{(s)} = \frac{d_i^{(s)} n_{li}^{(s)}}{n_i^{(s)}}.$$

Define

$$U_s = (U_1^{(s)}, \dots, U_{g-1}^{(s)})'$$

with

$$U_l^{(s)} = \sum_{m_s}^{i=1} (d_{li}^{(s)} - E_{li}^{(s)}) \text{ for } l = 1, \dots, g - 1.$$

Also, let V_s be a $(g - 1) \times (g - 1)$ covariance matrix with

$$V_{jl}^{(s)} = \sum_{m_s}^{i=1} \frac{d_i^{(s)} (n_i^{(s)} - d_i^{(s)}) n_{ji}^{(s)}}{n_i^{(s)} - 1} \left(\delta_{jl} - \frac{n_{li}^{(s)}}{n_i^{(s)}} \right) \text{ for } j, l = 1, \dots, g - 1$$

where

$$\delta_{jl} = \begin{cases} 1 & \text{if } j = l \\ 0 & \text{otherwise} \end{cases}.$$

Define

$$U = \sum_p^{s=1} U_s$$

and

$$V = \sum_p^{s=1} V_s.$$

The test statistic for the equality of the g survival functions is defined by

$$\chi^2 = U' V^{-1} U.$$

χ^2 has an asymptotic chi-square distribution with $(g-1)$ degrees of freedom.

19.3.4 Estimating Elephant Population from Dung Density Estimates

The dung density of elephants was converted into animal density using the following formula:

$$\text{Elephant density (No. / sq km)} = \frac{DD}{DR} \times DDR$$

where DD = dung density, DR = defecation rate, and DDR = dung decay rate

The defecation rate of 16.33 per day, as obtained from wild elephants in Mudumalai by Watve (1992), was used in the above formula. As far as dung decay rate is concerned, dung decay rate obtained from dung decay experiments conducted in Wayanad Elephant Reserve in 2005 alone was relied upon. The elephant population was extrapolated for various Elephant Reserves by multiplying density estimates with their respective extent of elephant habitat.

19.4 Results

19.4.1 Elephant Dung Survey

19.4.2 Dung Density Estimates Based on Line Transect Survey

Table 19.5 shows the dung density estimates for different Elephant Reserves irrespective of vegetation type.

19.4.3 Dung Decay Rate

A total of 624 dung piles were followed up in Wayanad Elephant Reserve. Of these, 151 dung piles were followed up in evergreen forests, 235 dung piles in moist/dry deciduous forests, and 238 in plantations. About 50% of the total observations were

Table 19.5 Estimated elephant dung density in different Elephant Reserves of Kerala State

Elephant reserve	Dung density (No. of dung piles/km ²)		% CV	
	2005	2007	2005	2007
Wayanad ER	1512 (1050–2176)	2124 (1514–2981)	18.45	17.14
Nilambur ER	468 (350–625)	930 (702–1232)	14.68	14.26
Anamudi ER	1307 (1074–1590)	1423 (1220–1660)	9.99	7.81
Periyar ER	857 (697–1055)	878 (750–1027)	10.54	7.99

Figures given in the parenthesis are 95% lower and upper confidence limit
SE standard error, *LCL* 95% lower confidence limit, *UCL* 95% upper confidence limit

found censored in each of the forest types. The age distribution of the dung piles marked and followed up in Wayanad Elephant Reserve shows that most of the dung piles were still surviving for more than 105 days (Table 19.6). Kaplan-Meier product limit estimates of the survivorship function and their standard errors were calculated at 15 days of time in each of the habitat types and presented in Table 19.7. The Kaplan-Meier survivorship function shown in Fig. 19.2 depicts a decreasing staircase function, dropped at the values of the observed failure times and constant between observed failure times; it also shows that there were many dung piles surviving for a longer time in the study period. The minimum probability value of the survivorship function is not zero since the largest observed time (105 days) is a censored observation.

The estimated quartiles of the survival time distribution can also be obtained from the estimated survivorship function. The estimated median survival time for all the habitat types was found to be $\hat{t}_{50} = 90$ days. This means that 50%, i.e., half of the dung piles, were estimated to decay within 90 days (Table 19.8). As most of the censored observations were skewed to the right (Fig. 19.2), the sample mean was not taken as an important central tendency, and hence median was considered as an appropriate measure of central tendency. The estimated median time to decay is 90 days, and thus decay rate is 0.0111.

An inspection of the proportion of values that are censored and the pattern of censoring from the graph (Fig. 19.2) indicates that the censoring experience of the three habitat types was similar. Thus it appears that the assumption, which is necessary for the tests for equality of the survivorship function, seems to hold. The results of the log-rank test (Table 19.9) revealed that there was no significant difference between habitat types with respect to the survival pattern of the dung piles ($p > 0.05$).

Table 19.6 Distribution of dung piles across different age groups in different vegetation types of Wayanad Elephant Reserve

Vegetation type	Age groups (in days)																				
	15		30		45		60		75		90		105								
	N	I	N	I	N	I	N	I	N	I	N	I	N	I							
Evergreen	10	0	10	12	7	5	16	12	4	23	17	6	37	25	12	24	14	10	29	1	28
Moist/dry deciduous	9	0	9	13	8	5	27	13	14	35	25	10	50	29	21	42	23	19	59	18	41
Plantation	13	0	13	17	5	12	30	15	15	33	16	17	55	48	7	38	25	13	52	16	36
Total	32	0	32	42	20	22	73	40	33	91	58	33	142	102	40	104	62	42	140	35	105

N Number of marked dung piles, *I* decayed, *I* not decayed (survived)

Table 19.7 Cumulative survival probability of the dung piles followed up in different vegetation types of Wayanad Elephant Reserve

Vegetation type	Time (in days)	Cumulative survival probability of the dung piles	Standard error	Cumulative number of dung piles disappeared	Number of dung piles remaining for follow-up
Evergreen	15	1.0000	–	0	151
	30	0.9504	0.0183	7	134
	45	0.8619	0.0294	19	117
	60	0.7323	0.0383	36	96
	75	0.5289	0.0443	61	65
	90	0.3892	0.0457	75	39
	105	0.3757	0.0460	76	28
Moist/dry deciduous	15	1.0000	–	0	235
	30	0.9646	0.0123	8	218
	45	0.9057	0.0196	21	200
	60	0.7840	0.0283	46	161
	75	0.6334	0.0340	75	122
	90	0.4892	0.0375	98	78
	105	0.3399	0.0391	116	41
Plantation	15	1.0000	–	0	238
	30	0.9778	0.0098	5	220
	45	0.9073	0.0198	20	193
	60	0.8257	0.0265	36	162
	75	0.5524	0.0368	84	97
	90	0.3989	0.0372	109	65
	105	0.2762	0.0363	125	36

19.4.4 Estimated Elephant Population Based on Dung Density

An attempt was made to estimate the elephant density and elephant population for different Elephant Reserves based on estimates of dung density, dung decay rate, and dung defecation rate. The pooled dung density estimates irrespective of vegetation types presented in Table 19.4 were used for estimating elephant density. The decay rate of 0.0102 per day from the experiments conducted in Wayanad Elephant Reserve in 2005 was used for both the census periods 2005 and 2007. With respect to defecation rate, 16.33 per day, as obtained from wild elephants in Mudumalai by Watve (1992), was used for estimating elephant density. The estimated elephant density and elephant population are presented in Table 19.10 for different Elephant Reserves.

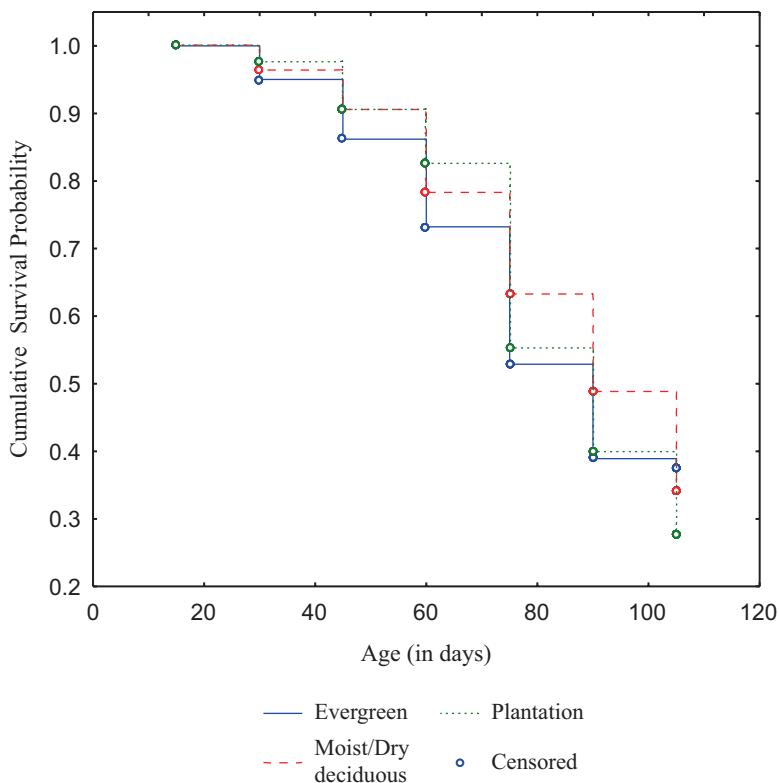


Fig. 19.2 Plots of estimated survivorship function for dung piles followed up in different vegetation types of Wayanad Elephant Reserve

Table 19.8 Kaplan-Meier estimates of survival time of the dung piles followed up in different vegetation types of Wayanad Elephant Reserve

Vegetation type	Mean survival time (SE)	95% confidence interval	Median survival time (SE)	95% confidence interval
Evergreen	82 (2)	78–86	90 (4)	82–98
Moist/dry deciduous	87 (2)	84–90	90 (4)	83–97
Plantation	85 (1)	82–88	90 (4)	83–97

SE standard error

Table 19.9 Log-rank statistic for testing the significance of the equality of the survivorship function in different vegetation types of Wayanad Elephant Reserve

Vegetation type	Evergreen	Moist/dry deciduous
Moist/dry deciduous	0.90	–
	($p > 0.05$)	
Plantation	0.00	1.46
	($p > 0.05$)	($p > 0.05$)

$p > 0.05$ indicates nonsignificant probability levels

Table 19.10 Estimated elephant density and elephant population in different Elephant Reserves based on dung density estimates

Elephant reserve	Elephant density (no. of elephants/km ²)		No. of elephants	
	2005	2007	2005	2007
Wayanad ER	0.9444	1.3271	882 (613–1270)	1240 (884–1739)
Nilambur ER	0.2923	0.5807	334 (250–446)	663 (501–879)
Anamudi ER	0.8161	0.8890	2299 (1889–2798)	2505 (2148–2921)
Periyar ER	0.5354	0.5484	1620 (1317–1994)	1660 (1418–1942)
Total			5135 (4069–6508)	6068 (4950–7481)

Elephant density was estimated with the decay rate of 0.0102 and the defecation rate of 16.33. Figures given in the parenthesis are 95% lower and upper confidence limit

19.5 Discussion

Line transect sampling requires proper placement of transects at random and accurate measurement of distance to dung piles. Large-scale surveys such as the present ones require a good training on field methods and proper monitoring of field work to improve the quality of the data. The experience of the analysts has also implications in choosing the appropriate key function and series expansion for estimating the dung density. Stratification is an important means by which the precision of the estimates can be improved. In the surveys conducted so far, prior stratification could not be effected for lack of information. The GIS technology enables to have the survey design drawn in the maps along with relevant details such as habitat type. In future censuses, such maps should be made available well ahead of the survey. The actual extent of elephant habitat is crucial in extrapolating elephant population. Therefore, concerted efforts should be made to estimate the actual extent of elephant habitat in each of the Elephant Reserves.

In estimating elephant population based on dung piles, dung decay rate is the most sensitive factor as it appears in the numerator part of the correction formula. Therefore, it is important that the dung decay rate is measured as precisely as

possible. There have been experiments conducted in the past with the assumption that the system is in steady state where the production rates are equal to the decay rates. With regard to the empirical technique used for determining decay rate, Barnes and Jenson (1987) fitted exponential decay rate equation with the assumption that the decay rate is independent of age. Later, Barnes and Barnes (1992) again estimated the dung decay rate using some other equations assuming constant and variable age-specific mortality following curve-fitting approach. Recently, Laing et al. (2003) suggested a retrospective method, which does not have steady-state assumption and proposed logistic regression technique for the analysis of data. In our study, though this methodology was followed, we could not adopt logistic regression technique for determining decay rate, as the number of zeroes (disappearance of dung piles) was not sufficient over the study period. Therefore, a different analytical approach had to be followed for estimating the dung decay rate. We found Kaplan-Meier product limit function as an appropriate method. In this technique, time is treated as a major outcome variable and is nonparametric and therefore avoids many of the statistical problems of other techniques. Further it takes into account the survival time information available on censored observations unlike other techniques. To be more precise, the survival analysis takes into consideration the dung piles that are contributed to the number at risk along the time horizon until they are lost to follow up (Table 19.7).

Dung decay rate highly varies across sites. Only a very few experiments have been conducted in India. The estimated decay rate in our study is 0.0102 for all the vegetation types in Wayanad Elephant Reserve. The dung decay experiments conducted earlier in Wayanad Wildlife Sanctuary reported the decay rate of 0.0191 during dry season and 0.0360 during wet season (Easa 1999). Sale et al. (1990) reported an overall decay rate of 0.0136 during dry season in the same area and decay rate of 0.0146 during early dry season in Parambikulam Wildlife Sanctuary. Varman et al. (1995) reported a dung decay rate of 0.010 in dry season and 0.013–0.007 in wet season in Mudumalai Sanctuary. For African elephants, Barnes and Barnes (1992) obtained an elephant dung decay rate of 0.0026 based on exponential curve and 0.022 based on modeling variable age-specific mortality of dung piles. The decay rate obtained by White (1995) varied from 0.013 to 0.007.

Dung decay rate is highly affected by a number of factors such as rainfall (Barnes et al. 1997; Barnes and Dunn 2002), relative humidity, canopy cover, sunlight, amorphous dung, boli volume, and content of dung (grass fragments, leaf fragments, fruit fibers, and hard seeds) along with activities of mammals and birds (Nchanji and Plumptre 2001). The statistical technique adopted by Nchanji and Plumptre (2001) for the analysis of data was multiple linear regression technique with the duration of dung piles as dependent variable. In the recent past, the proportional hazard model is used for analyzing survival data that can also be tried in large-scale dung decay experiments where censoring occurs (Hosmer and Lemeshow 1999). It does not assume the nature or shape of the underlying survival distribution. It only assumes that the underlying hazard rate is a function of independent variables (covariates). Thus it may be considered as a nonparametric. Nonetheless, the model has two assumptions: (1) multiplicative relationship between the underlying

hazard function and the log-linear function of the covariates (proportionality assumption) and (2) log-linear relationship exists between the independent variables and the underlying hazard function. If the covariates can have different values at different points in time for the same case (e.g., relative humidity), then covariate is dependent on time, and hence Cox regression with time-dependent covariates is suggested to use. The advantage of Kaplan-Meier over the Cox's proportional hazard model is that the latter is a model dependent and needs a mathematical function to express.

It must be noted that the dung decay rate used in 2005 was based on dung decay experiments conducted during 2005 census in Wayanad Elephant Reserve alone. The same decay rate was again used in 2007. In order to improve the estimates, it is necessary that the dung decay experiments are conducted in all the Elephant Reserves representing different habitat conditions. The sampling effort in terms of number of blocks chosen for the dung survey was increased significantly from 34% in 2005 to 50% in 2007. Despite methodological and coverage issues, results of 2005 and 2007 surveys were compared. The estimated elephant population of the State using dung survey for the census year 2007 was 6068. This is higher than the estimated population of 5135 elephants in the year 2005. An increasing trend in elephant population was seen in all the Elephant Reserves.

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