

Research Article

Estimating Asian elephant, *Elephas maximus*, density through distance sampling in the tropical forests of Biligiri Rangaswamy Temple Tiger Reserve, India

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Abstract

To determine abundance, density and distribution of wild animals, it is crucial to estimate populations using reliable sampling techniques. In most earlier studies, elephant populations were estimated employing block counts or dung counts, which provide biased estimates due to limitations of the methods. We estimated an Asian elephant population using distance sampling, a quantitatively robust technique, in Biligiri Rangaswamy Temple Tiger Reserve, a critical elephant conservation area in the Nilgiri Biosphere Reserve in south India. We laid 33 transects with a total length of 93 km. We walked these transects five to 11 times amounting to a total of 795.5 km of walks. We collected data on location, number and age-sex classes through direct elephant sightings, using rangefinders, global positioning systems and compass. We used DISTANCE software for analysis. We estimated per km² cluster density as 0.69 elephant herds, mean cluster size as 2.44, and elephant density as 1.7 animals. This amounts to a total of 713 elephants in 610 km² of the sanctuary. A high percentage of males less than 30 years old and a low immature:adult female ratio indicated the severity of poaching in the recent past in the study region.

Keywords: Asian elephant, BRT Tiger Reserve, distance sampling, density

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Introduction

Population estimation, either by direct (observations) or indirect (nest or faecal) surveys, is crucial to determine abundance, density and distribution of wild animals [1-3]. In the case of large-bodied animals such as elephants, use of line transects based on direct sightings or indirect signs such as dung have been commonly applied to estimate density in the wild [4-6]. Other methods, such as mark-recapture and water hole count, have seldom been used to estimate density of wild elephants [2, 7-10]. In India, estimates of elephant densities in the forest areas often relied heavily on line transect dung count and block count methods [11]. However, these methods lack a strong theoretical basis and do not statistically address critical problems such as probability of detection of animals within the surveyed area. Further, use of the dung count method to estimate elephant densities is often limited by using known defecation rates [11] which are affected by factors such as season, rainfall, habitat types, size of boli etc. [12-13] or on the assumption of age-specific decay rates [14], thereby providing biased estimates. Population parameters such as density and age-sex ratios have also been estimated using distance sampling based on direct or indirect signs [15], capture-recapture [16] and population surveys [4]. More recent methods such as photographic techniques and acoustic sensors have seldom been used to estimate abundance of elephants in dense forest areas [7, 17-18]. Distance sampling offers a reliable estimation of animal densities [19] comparable to results of the mark-recapture method, and has also proved to be cost-effective and less disturbing to the environment [20].

The Asian elephant (*Elephas maximus*) is highly threatened by habitat fragmentation, habitat loss and human-elephant conflict in many parts of Asia [21-24]. In India, which hosts 60% of the global Asian elephant population, nearly two-thirds of the elephant population lives either close to or within human-dominated landscapes [25-26]. Southern India harbors half of India's Asian elephant population [27], and its Nagarhole-Nilgiris-Eastern Ghats Elephant Reserve, containing about 6300 elephants in an area of 12,000 km² [28], is an important conservation area with large wild lands available for elephants. However, these areas are also threatened by the development network and human density [25].

The Biligiri Rangaswamy Temple (BRT) Tiger Reserve within the Nilgiri Biosphere Reserve is a critical place for elephant conservation. There have been no standardized estimates of Asian elephants in BRT for the past three decades due to insurgency created by forest brigands. The available estimates are based on the state Forest Department's annual census programs, which were not based on spatially representative sampling efforts and tended to project unreliable densities [29]. However, in the adjoining forests of BRT in the Nilgiri Biosphere Reserve, elephant densities have been estimated to be 3.3 animals per km² [30] in Nagarhole Tiger Reserve and 4.41 elephants per km² in Mudumalai Tiger Reserve [31]. Earlier predictions of elephant densities using the dung-count method indicate 2–4 elephants per km², amounting to a total of 691-914 elephants in the BRT hills [28]. In order to provide more reliable results, we here report the abundance estimate of elephants using the distance sampling method with a special emphasis on age-sex ratios in the tropical forests of BRT. This information will serve two purposes. It will indicate the importance of this area and place it in a larger elephant conservation program surrounding this region. It will also provide base data for the future study of elephant population dynamics and development of effective conservation strategies.

Methods

Study area

We carried out this study in the Biligiri Rangaswamy Temple Tiger Reserve, which lies between $11^{\circ} 40' - 12^{\circ} 09' N$ and $77^{\circ} 05' - 77^{\circ} 15' E$, covering an area of 610 km^2 (Fig. 1). The altitude in this area varies between 600 m asl to 1800 m asl. The temperature varies spatially and temporally, with the minimum temperature between $8^{\circ} C$ to $16^{\circ} C$ and the maximum temperature between $20^{\circ} C$ to $38^{\circ} C$. Rainfall varies from year to year in intensity and distribution, with the plateau lands receiving as low as 600 mm and the upper hills receiving over 3000 mm. The wide range of climatic conditions also contributes to the heterogeneous assemblage of habitats such as scrub, deciduous, riparian, evergreen, sholas, grasslands etc. The major forest types are evergreen forest (EF, 10.3%, which include evergreen forests, sholas and high altitude grass lands), moist deciduous forest (MDF, 25%), dry deciduous forest (DDF, 36.1%) and scrub forest (SF, 28.2%) [32]. There are many human enclaves inside the sanctuary, including settlements of indigenous people, temple staff, and private estates of commercial plantations growing coffee *Coffea arabica*, pepper *Piper nigrum*, cardamom *Elettaria cardamomum* etc.. Over 6000 tribal people living in 57 settlements in the sanctuary have caused high biotic pressure [33].

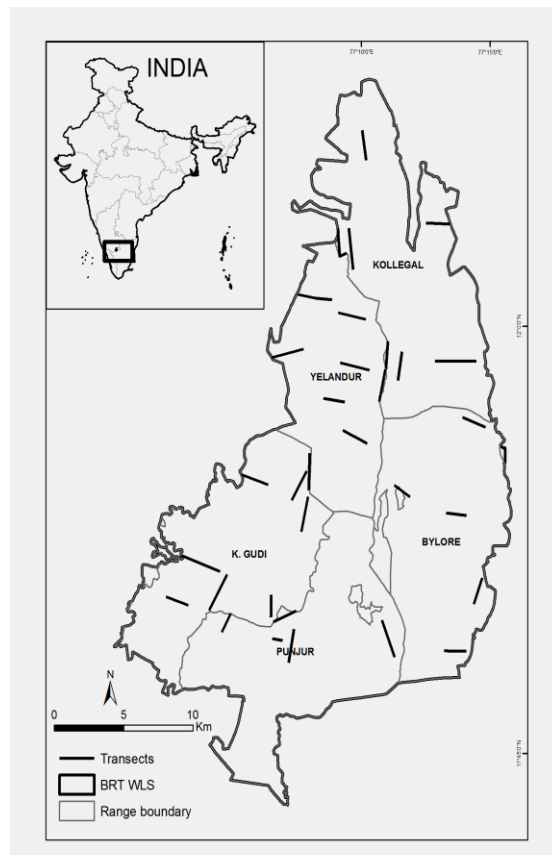


Fig. 1 Map showing the transects in the BRT Tiger Reserve

Sampling methods

We used a combination of methods by adding 26 new random line transects to the seven existing transects being used for annual census by the Karnataka Forest Department. The length of transects ranged from 2 to 4 km, totaling a distance of 93 km. We made five to 11 repeated walks on transects [34], between 06.00 and 10.00 h and from 16.30 to 18.30 h during October 2009 and April 2010, as the visibility during these months is better than during the monsoon season between May and September. We walked a total of 795.5 km on the transects. During a transect walk, we recorded data on sightings of single individuals, number of individuals and their age- sex if sighted in a herd, animal-to-observer distance, and angle of detection from main bearing. We measured observer-to-animal distance using OPTI-LOGIC 1000 XL and OSPREY rangefinders, and the angle of detection from the transect line using a compass. When elephants were encountered in a herd (animals aggregating within 30 m radius) [30]), we recorded distance and angle to the centre of the herd. We recorded the coordinates for each sighting using handheld GARMIN eTrex H and GARMIN 72 GPS units.

We analyzed the data using DISTANCE version-5 [35] software and computed the estimate of density. We pooled the data from temporal replicates of each transect and treated the mean as a single sample (sample size = 33). We truncated the farthest sightings on transect to achieve a reliable density estimate [36]. However, we performed the density estimates using both truncated and un-truncated data. Checking for size bias in detection of animal clusters led to a non-significant regression equation at $\alpha = 0.10$ [37], and we therefore used the mean cluster size for analysis. We estimated variance in encounter rates of animals between transects empirically [36]. We judged the fit of possible alternative models to each specific dataset using Akaike's information criterion (AIC) value and goodness of fit tests generated by the program DISTANCE, and selected the best possible model. We generated encounter rate, average probability of detection, cluster density, cluster size and animal density using the selected model in program DISTANCE. For sightings in which age-sex of individuals could not be recorded, we recorded only group size. We divided animals into three age-sex classes, classifying animals younger than age 15 as immature and the rest as adult males and adult females following the indicators by Sukumar et al. [38].

Results

We recorded a total of 46 sightings of elephants on line transects. Data did not show heaping (Fig. 2). The estimate of cluster was 0.69 elephant herd per km^2 with a mean cluster size of 2.44 (Table 1). The density of individuals was estimated to be 1.7 elephants per km^2 (95% confidence interval of 1.17-2.46 elephants per km^2) and the percent coefficient of variation of density of individuals was 18.97. The minimum population density of 1.17 elephants per km^2 accounts for 713 elephants (lower CI) in BRT.

Table 1. Density estimate for elephants in the Biligiri Rangaswamy Temple Tiger Reserve

Data type	Sightings	Clusters/ km^2	Mean cluster size	Density/ km^2	% coefficient of variation	95%CI/ km^2
Untruncated	46	0.68	2.60	1.78	16.93	1.27-2.48
Truncated	44	0.69	2.44	1.70	18.97	1.17-2.46

The sightings ranged between 1 and 6 elephants with a mean of 2.4 ± 1.44 (SD) elephants. Numbers of sightings in each size category are presented in Fig. 3. About 40% of the sightings were of single individuals. Most of these individuals were males, though a few solitary females were also sighted. About 70% of the adult males appeared to be less than 30 years old. The percentages of adult males, adult females and immature were 15.2, 62.9 and 22.0, respectively. This provided a ratio of 1:4.1 for adult males and females, and 1:0.35 for adult females to immature.

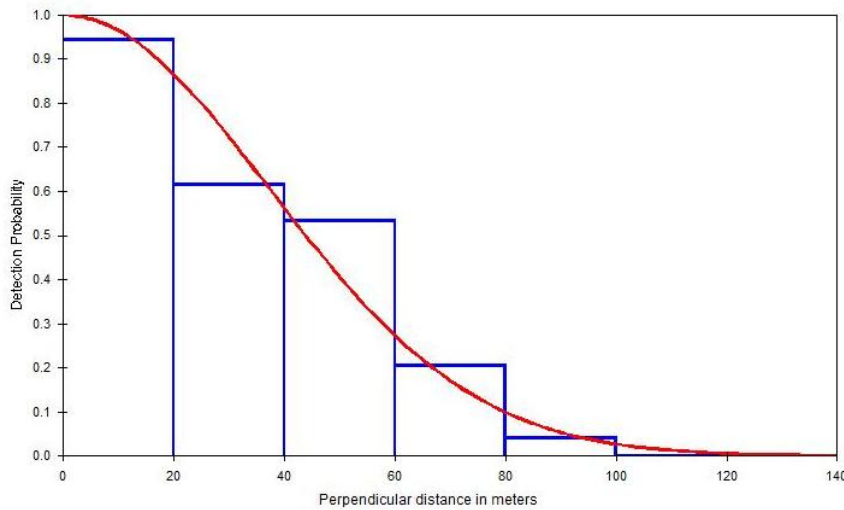


Fig. 2 Detection distances of elephants in BRT Tiger Reserve (for un-truncated data)

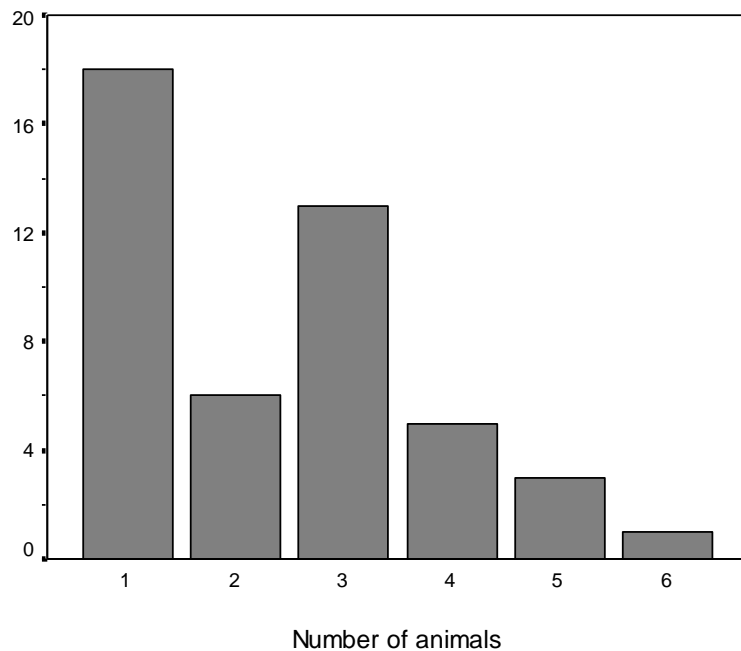


Fig. 3 Number of sightings of elephants in each size category

Discussion

The population estimate of wild Asian elephants in range countries has been a matter of debate. Recent estimates of Asian elephants in India range between 27,669 and 27,719 [39]. The Project Elephant has officially declared 32 elephant reserves with an area of 60,000 km² to protect elephants, their habitats and corridors. Estimation of elephant densities has been crucial for designing appropriate management options for conservation of Asian elephants in protected areas. The current estimate for BRT is comparable to earlier studies [28]. Most of the estimates for Asian elephants in India are primarily based on intensive studies carried out at the regional level. The Nilgiri Biosphere Reserve (NBR), which accounts for the largest elephant population in India, occupies an important conservation area for elephants. The BRT Tiger Reserve within the NBR has not been rigorously studied to estimate elephant population for nearly three decades. However, as a part of synchronized elephant census program, a recent estimate of elephant population by using the transect dung/block count methods in BRT revealed 1.4 elephants/km² and 0.8 elephants/km², respectively, compared to the adjoining areas of Bandipur Tiger Reserve (1.8 elephants/km²), Nagarahole National Park (1.6 elephants/km², [15]), Mudumalai Tiger Reserve (3.1/ km²), Nilgiri north (0.5/ km²), Satymangalam (0.3/ km², [40]), and Wayanad Wildlife Sanctuary (1.75/ km², [41]).

The above two methods have not been tested for scientific credence and have certain key limitations: (a) difficulty in counting all animals in a sample block, (b) observer's skill and experience and (c) assumption of detectability to be 1. The dung count method is usually carried out during the summer/dry period due to logistics and convenience, which causes biases in elephant density estimation [12]. Moreover, two of the three parameters (dung defecation and dung decay rates) in the dung count method have not been calculated prior to census [15] and are often used from earlier efforts carried out elsewhere. Liang *et al.* [42] and Hedges & Lawson [43] pointed out that dung decay rates vary by up to 72% across localities, seasons, and years in the same area. These shortcomings warrant use of other methods, such as line transect for direct observations of elephants/elephant herds, mark-recapture, photography, etc., to estimate elephant densities [7, 30-31]. This study produced a reliable estimate of elephants through direct observations on line transects that were repeatedly walked over a considerable period of time. The study estimated that there are around 700 elephants in BRT.

Whereas a substantial proportion of sightings was of solitary individuals, most of the herds sighted ranged between 2 and 4 individuals. Most of the adult males appeared to be less than 30 years old, suggesting the disappearance of old bulls due to poaching by forest brigands who operated in the Tiger Reserve for over three decades. This has possibly affected the distribution of elephants and resulted in small family units of a mother and dependent offspring in response to anthropogenic pressure [27, 44], which is a serious concern in the BRT. On other hand, it has been clearly established that mating success of bulls is highly dependent on the presence of the oldest males, which performed most of the mating and fathered the majority of infants in elephant herds [45].

Implications for conservation

Poaching pressures may seriously lower the infant-to-female ratio by affecting birth rates and disturbing the demographic structure, inhibiting the long-term survival of elephants [46, 47]. The skewed ratios of adult female to young may be due to heavy poaching pressures over a long period of time in the BRT. Likewise the 1:4.1 adult male to adult female ratio in BRT also reflects

severe poaching on male elephants as the normal male to female ratios for elephants are considered to be 1:1.87 and 1:1.85 as reported for Rajajai National Park of India [48] and Ruhuna National Park of Sri Lanka [49] respectively.

Since the precise status of elephant densities and age-sex structure for the BRT conservation region was not available before now, the data reported in this article should become a starting point for enumerating elephant population dynamics and designing conservation programs accordingly.

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References

- [1] Jathanna, D., Karanth, K. U. and Johnsingh, A. J. T. 2003. Estimation of large herbivore densities in the tropical forests of southern India using distance sampling. *Journal of Zoology* 261: 285–290.
- [2] Rasmussen, H. B., Kahindi, O. and Douglas-Hamilton, I. 2005. Estimating elephant densities in wells and river beds in dried out beds. *African Journal of Ecology* 43: 312–319.
- [3] Varma, S., Pittet, A. and Jamadagni, H S. 2006. Experimenting usage of camera-traps for population dynamics study of the Asian elephant *Elephas maximus* in southern India. *Current Science* 91: 324–331.
- [4] Sukumar, R. 1986. The elephant populations of India-strategies for conservation. *Proceedings of Indian Academy of Science (Suppl.)*, 59-71.
- [5] Barnes, R. F. W., Blom, A., Aler, M. P. T. and Barnes, K. L. 1995. An estimate of the numbers of forest elephants in Gabon. *Journal of Tropical Ecology* 11: 27 – 37.
- [6] Alfred, R., Ahmad, A. H., Payne, J., Williams, C. and Ambu, L. 2010. Density and population estimation in Bornean elephants (*Elephas maximus borneensis*) in Sabah. *Online Journal of Biological Science* 10: 92–102.
- [7] Goswami, V. R., Madhusudan, M. D. and Karanth, K. U. 2007. Application of photographic capture–recapture modeling to estimate demographic parameters for male Asian elephants. *Animal Conservation* 10: 391–399.
- [8] Morley, R. C, and van Aarde, R. J. 2007. Estimating abundance for a savanna elephant population using mark-resight methods: a case study from the Tembe Elephant Park, South Africa. *Journal of Zoology* 271: 418-427.
- [9] Chamaille-James, S., Fritz, H., Valeix, M., Murindegomo, F. and Clobert, J. 2008. Resource variability, aggregation and direct density dependence in an open context: the local regulation of an African elephant population. *Journal of Animal Ecology* 77: 135-144.

- [10] Jennifer, P., Nishantha, H. G., Janaka, H. K., Isler, K. and Fernando, P. 2010. Water-body use by Asian elephant in souther Sri Lanka. *Tropical Conservation Science* 3: 412–422.
- [11] Kumaraguru, A., Karunanithi, K., Asokan, S and Baskaran, N. 2010. Estimating Asian elephant population in Dindugal, Kodaikanal, and Theni forest divisions, Western Ghats, Tamil Nadu. *Gajah*, 32: 35 – 39.
- [12] Olivier, P. I., Ferreira, S. M. and van Aarde, R. J. 2009. Dung surveys bias and elephant population estimates in southern Mozambique. *African Journal of Ecology* 47: 202–213.
- [13] Theurakuf, J. and Gula, R. 2010. Towards standardization of population estimates: defecation rates of elephants should be assessed using a rainfall model. *Ann. Zool.Fennici*. 47, 398– 402.
- [14] Barnes, R. F. W. and Barnes, K. L. 1992. Estimating decay rates of elephant dung piles in forest. *African Journal of Ecology* 30: 316 – 321.
- [15] Baskaran, N. and Sukumar, R. 2011. Karnataka elephant census 2010. Asian Nature Conservation Foundation and Indian Institute of Science technical report: Bangalore.
- [16] Williams, A. C. 2002. Elephants (*Elephas maximus*), their habitats in Rajaji – Corbett National Park. *PhD Thesis*. Saurashtra University, Rajkot.
- [17] Thompson, M. E., Schwager, S. J. and Payne, K. B. 2009. Heard but not seen: an acoustic survey of African forest elephant population at Kakum Conservation Area, Ghana. *African Journal of Ecology* 48: 224 – 231.
- [18] Thompson, M. E., Schwager, S. J. Payne, K. B. and Turkalo, A. K. 2010. Acoustic estimation of wildlife estimation: methodologies for vocal mammals in forested habitats. *African Journal of Ecology* 48: 654 – 661.
- [19] Sridhar, H., Raman, T. R. S. and Mudappa, D. 2008. Mammal persistence and abundance in tropical rainforest remnants in southern Western Ghats, India. *Current Science* 94: 748–757.
- [20] Cassey, P. 1999. Estimating animal abundance by distance sampling techniques. *Conservation Advisory Science Notes* 1 – 12.
- [21] Sukumar, R. 1990. Ecology of Asian elephant in southern India—II. Feeding habits and crop raiding patterns. *Journal of Tropical Ecology* 6: 33–55.
- [22] Desai, A. A. 1991. The home range of elephants and its implications for management of the Mudumalai Wildlife Sanctuary, Tamilnadu. *Journal of Bombay Natural History Society* 88:145–156.
- [23] Madhusudan, M. D. 2003. Living amidst large wildlife: livestock and crop depredation by large mammals in the interior villages of Bhadra Tiger Reserve, south India. *Environmental Management* 31: 466 – 475.
- [24] Kumar, M. A., Mudappa, D. and Raman, T. R. S. 2010. Asian elephant *Elephas maximus* habitat use and ranging in fragmented rainforest and plantations in the Anamalai Hills, India. *Tropical Conservation Science* 3:143–158.
- [25] Leimgruber, P., Gagnon, J. B., Wemmer, C., Kelly, D. S., Songer, M. A. and Selig, E. R. 2003. Fragmentation of Asia's remaining wild lands: implications for Asian elephant conservation. *Animal Conservation* 6: 347–359.
- [26] Sukumar, R. 2006. A brief history of the status, distribution, and biology of wild Asian elephant *Elephas maximus*. *International Zoo Yearbook* 40: 1 – 8.
- [27] Sukumar, R. 2003. *The living elephants: evolutionary ecology, behavior, and conservation*. Oxford University Press: New York.
- [28] Asian Elephant Research and Conservation Centre. 1998. The Asian elephants in southern India: A GIS database for conservation of Project Elephant Reserves. Bangalore: Asian Elephant Research and Conservation Centre.

- [29] Blake, S. and Hedges, S. 2004. Sinking the flagship: the case of forest elephants in Asia and Africa. *Conservation Biology* 18: 1191–1202.
- [30] Karanth, K. U. and Sunquist, M. E. 1992. Population structure, density and biomass of large herbivores in the tropical forests of Nagarahole, India. *Journal of Tropical Ecology* 8: 21-35.
- [31] Varman, K. S. and Sukumar, R. 1995. The line transects method for estimating densities of large mammals in a tropical deciduous forest: an evaluation of methods and field experiments. *Journal of Bioscience* 20, 273-287.
- [32] Ramesh, B. R. 1989. *Flora of Biligirirangan Hills*. Ph.D. thesis. Madras, University, Madras, India.
- [33] Barve, N., Kiran, M. C., Vanaraj, G., Aravind, N. A., Rao, D., UmaShankar, R., Ganeshaiah, K. N. and Poulsen, J. G. 2005. Measuring and mapping threats to a Wildlife Sanctuary in southern India. *Conservation Biology* 19: 122-130.
- [34] Plumptre, A. J. 2000. Monitoring mammalian populations with line transect techniques in African forests. *Journal of Applied Ecology* 37: 356–368.
- [35] Laake, J. L., Buckland, S. T., Anderson, D. R. and Burnham, K. P. 1994. *DISTANCE: user's guide, V 2.1*. Colorado Co-operative Fish and Wildlife Research Unit, Colorado State University: Fort Collins, CO.
- [36] Buckland, S. T., Anderson, D. R., Burnham, K. P. and Laake, J. L. 1993. *Distance sampling*. Chapman and Hall: London and New York.
- [37] Drummer, T. D. and McDonald, L. L. 1987. Size bias in line transect sampling. *Biometrics* 43: 13-21.
- [38] Sukumar, R., Joshi, N. V. and Krishnamurthy, V. 1988. Growth in the Asian elephant. In: *Proceedings of Indian Academy of Science (Animal Sciences)*. 97, 561-571.
- [39] Project Elephant 2010. Estimated population of wild elephants for the year 2007 – 08. <http://envfor.nic.in/pe/elephant2007.pdf>. Accessed on 21 June 2010.
- [40] The Tamil Nadu Forest Department (Wildlife Wing). 2010. Population estimates of Asian elephants in the elephant reserves of Tamil Nadu. *Synchronized elephant census technical report*. Pp 29.
- [41] The Kerala Forest Research Institute. 2007. Population estimation of wild elephants in the elephant reserves of Kerala state. *KFRI extension report 27*. Pp. 40.
- [42] Laing, S. A., Buckland, S. T., Burn, R. W., Lambie, D. and Amphlett, A. 2003. Dung and nest surveys: estimating decay rates. *Journal of Applied Ecology* 40:1102–1111.
- [43] Hedges, S. and Lawson, D. (editors) 2006. Dung survey standards for the MIKE programme. Monitoring the illegal killing of elephants. CITES MIKE Programme: Kenya.
- [44] Barnes, R. F. W., Barnes, K. L., Alers, M. P. T. and Blom, A. 1991. Man determines the distribution of elephants in the rain forests of north eastern Gabon. *African Journal of Ecology* 29: 54-63.
- [45] Ishengoma, D. R. S., Shedlock, A. M., Foley, C. A. H., Foley, L. J., Wasser, S. K., Balthazary, S. T. and Mutayoba, B. M. 2008. Effects of poaching on bull mating success in a free ranging African elephant (*Loxodonta africana*) population in Tarangire National Park. Tanzania. *Conservation Genetics* 9: 247–255.
- [46] Sukumar, R., Ramakrishnan, U. and Santosh, J.A. 1998. Impact of poaching on Asian elephant population in Periyar, southern India: a model of demography and tusk harvest. *Animal Conservation* 1: 281 – 291.
- [47] Foley, C. A. H., Papageorge, S. and Wasser, S. K. 2001. Non-invasive measures and reproductive measures of social and ecological pressures in free ranging African elephants. *Conservation Biology* 14: 1134-1142.

- [48] Williams, C., Johnsingh, A. J. T. and Krausman, P. R. 2007. Population estimation and demography of the Rajaji National Park elephants, North-West India. *Journal of Bombay Natural History Society* 104:145-152.
- [49] Katugaha, H. I. E., deSilva, M. and Santiapillai, C. 1999. A long term study on the dynamics of the elephant (*Elephas maximus*) in Ruhuna National Park, Sri Lanka. *Biological Conservation* 89:51-59.