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Ekológia (Bratislava) - Journal of the Institute of Landscape Ecology, Slovak Academy of Sciences Vol. 44, No. 2, p. 169–175, 2025

DOI:10.2478/eko-2025-0019

ASIAN ELEPHANT (*Elephas maximus*) POPULATION STATUS AND DEMOGRAPHY IN TROPICAL FOREST OF SOUTH INDIA

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Received: 4 May 2024 / **Accepted:** 30 November 2024

Abstract

Ashokkumar M., Sakthivel C., Sudhakar K.: Asian elephant (*Elephas maximus*) population status and demography in tropical forest of South India. Ekológia (Bratislava), Vol. 44, No. 2, p. 169–175, 2025

Assessing the population dynamics and demography of long-lived species can be challenging due to longer lifespans and slow reproductive rates. The population status and demography of the Asian elephant was studied from Dec 2006 to May 2008 at Mudumalai Tiger Reserve. The results were compared with previous studies (1985 and 2000) conducted in the study area to understand temporal changes in the elephant population. Distance sampling and mark-recapture methods were used to estimate elephant density in wet and dry seasons. A total of 651.5 km was sampled using transect method. For the capture–recapture method, 17 routes were monitored fortnightly. The sampling effort was 128.5 km. The estimated elephant density based on capture–recapture and distance sampling was 3.4 and 3.6/km^2 respectively. The current estimate is higher than previous estimate (1/km^2 in 1985 and 2.4/km^2 in 2000). The adult male to adult female ratio was 1:20. Tuskless male makhnas accounted for 20% of the male population. Demography data showed that there has been an increase in the number of males in the population. However, the lack of older bulls in the population and the mortality of males through retaliatory killing require further investigation. Natural causes such as disease, injuries, and predation by tigers (two calves) accounted for a major percent (61%) of mortality. Sex-biased changes in mortalities have occurred over time. While adult and sub-adult male mortalities were higher (83%) in the earlier study period, adult female mortalities were higher (54.5%) in the present study. Despite the skewed sex ratio, elephant population has increased in the study area.

Key words: Asian elephant, population, demography, capture–recapture method, Mudumalai Tiger Reserve, elephant mortality.

Introduction

The Asian elephant (*Elephas maximus*) is listed as an endangered species, with 60% of the population occurring in India. The estimated population ranges between 48,323 and 51,680 elephants distributed in 13 countries across Asia (Williams et al., 2020; Riddle et al., 2010). They have long life spans, a slow reproduction rate, and they live in forest habitats, thereby making observations in the wild difficult. Therefore, demographic status is difficult to obtain, and most populations are not monitored over the long term. The elephant population in the tropical forest of South India was estimated using various methods in the past. The total count method was used by the forest department from 1970 until 1980. In the later 1980s, the ratio method was used to estimate populations using the ratio between known and unknown elephants encountered during the study (Daniel et al., 1987). In the 1990s, population size was determined using factors such as defecation and decay rate in the line transect indirect method (dung count) by Dawson (1990). Varman and Sukumar (1995) studied the various parameters of the direct count method in the study area.

The Tamil Nadu Forest Department has been using the distance sampling methods (both direct and indirect counts) and block count to estimate the population of larger mammals, especially elephants and other large herbivores since 1995. However, these efforts have been hampered by poor survey design and lack of equipment such as range finders and field compasses. Trained personnel are needed to ensure the accuracy of the estimate. In the 2000s, the elephant population in India was estimated using the direct block count and indirect count methods (Bist 2003; Rangarajan et al., 2010). In this study, we used distance sampling, capture–recapture method, and the ratio method (for comparison with earlier studies) to estimate the elephant population. Once precise and accurate population estimates were made, we explored population trends of these elephants and endeavored to understand the changes that have taken place in the elephant population over the last three decades in the Mudumalai Tiger Reserve (MTR).

Methods

Study area

MTR is in the Nilgiri District of Tamil Nadu (11º 32´ and 11º 42´ N and 76º 20´ and 76º 45´ E). It extends over an area of 321 km² and forms a part of the Nilgiri Biosphere Reserve (Fig. 1). The sanctuary is in the Western Ghats, which is one of the 35 Biodiversity hotspots of the world (Myers et al., 2000). Altitude in the study area varies from 485 to 1226 m above Mean Sea Level with a general elevation of about 900–1000 m. The annual rainfall varies from 1001 to 1648 mm. This sanctuary receives rain from both southwest (May to August) and northeast (September to December) monsoons. There are three distinct seasons in the area: dry season (January to April), first wet season (southwest monsoon), and second wet season (northeast monsoon). The study area has three major forest types, namely tropical moist deciduous forest, dry deciduous forest, and tropical thorn forest (Champion and Seth 1968). The large herbivores include elephant *Elephas maximus*, three species of cervids: chital *Axis axis*, sambar deer *Rusa unicolor,* and barking deer *Muntiacus muntjak*, two species of antelopes: the four-horned antelope *Tetracerus quadricornis* and the blackbuck *Antilope cervicapra*. In addition, predators like tiger *Panthera tigris*, leopard *P. pardus,* and wild dog *Cuon alpinus* are found. MTR is threatened by habitat degradation from overgrazing, poaching, and human disturbance.

The study area is a part of Elephant Range-7, which is one of the 11 elephant ranges, declared by Project Elephant (Govt. of India). This range extends over 12,900 km² of forest in the Western and Eastern Ghats. It has a tenuous link with Elephant Range-8, which covers an area of 2385 km², and it has been confirmed that there is a movement of elephants between elephant ranges 7 and 8 (Baskaran et al., 1995). These ranges together cover an area of 15,000 km² and support a population of 14,000 elephants (Riddle et al., 2010). The large, contiguous area is home to the largest single Asian elephant population in Asia.

Distance sampling

Elephant density was estimated using the line transect direct count method (Buckland et al., 2001), which is widely used to assess ungulate populations in tropical forests (Karanth, Sunquist, 1992; Varman, Sukumar, 1995; Baskaran, Desai, 2000; Jathanna et al. 2015). The sample design was similar to that of Baskaran and Desai (2000), which involves initially stratifying the study area based on habitat type and also on human disturbance as this influences elephant distribution (Desai, Baskaran, 1996).

A grid was developed using 4 km² blocks and overlaid with a stratified vegetation map of the study area. Out of a total of 80 grid squares, 35 grids were randomly selected for sampling. In the selected grids, a transect was laid and the direction of the transect varied according to the topography of the area (Fig. 1).

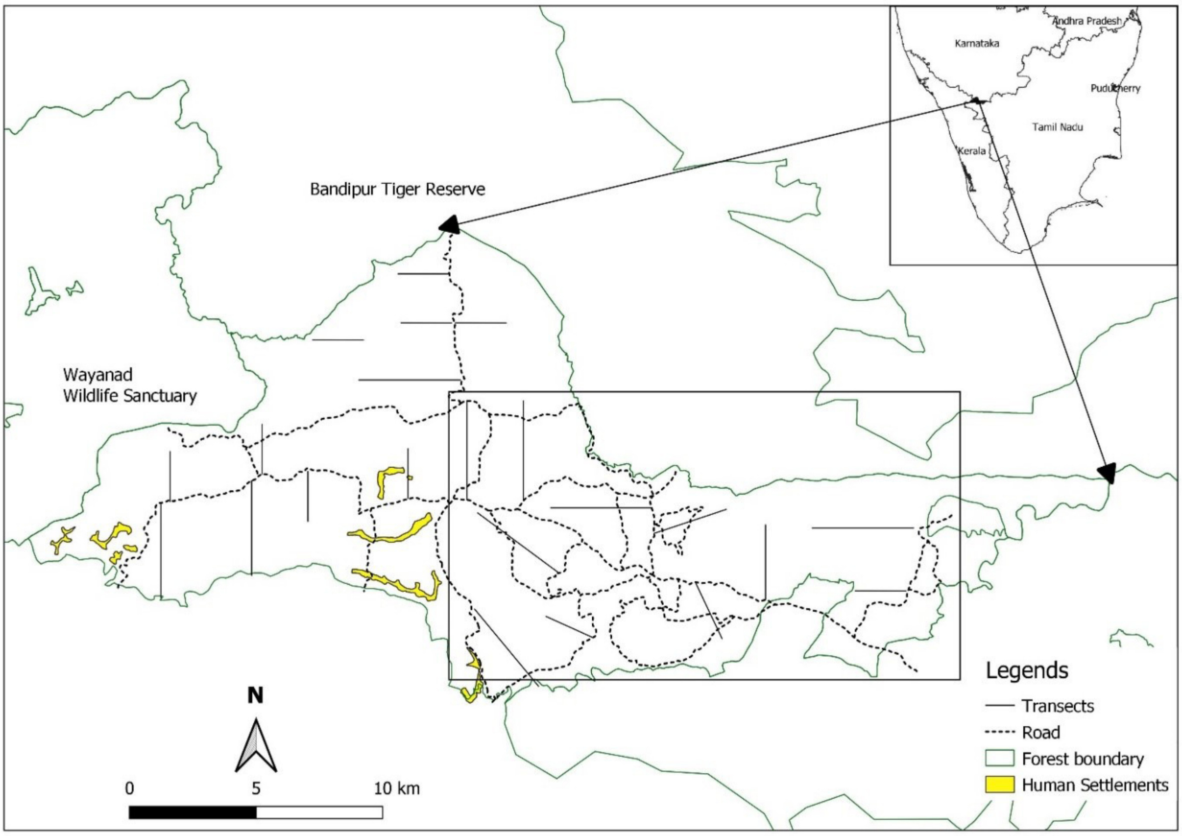

Fig. 1. Map of Mudumalai Tiger Reserve showing the locations transect lines and survey routes (inset rectangle) for mark-recapture sampling.

Transects were randomly laid to ensure that spatial variability within these sub-areas was adequately sampled. In total, 24 transects of 2- and 4-km lengths were used for sampling. A total distance of 651.5 km was walked in different seasons (dry-2007: 225.5 km; wet-2007: 140 km; dry-2008: 286 km). Vegetation modification to facilitate movement (while sampling) along these transects was kept to a minimum to avoid biases caused by either attraction or avoidance of animals.

Exploratory analysis of the distance data was carried out, as prescribed by Buckland et al. (2001), looking for evidence of evasive movement before detection, rounding, and heaping of data to truncate outlier observations and to improve subsequent model fitting. Data were analyzed using the program Distance 7.2 software (Buckland et al., 2001; Thomas et al., 2010). The fit of possible alternative models to each specific dataset was judged using Akaike's Information Criterion (AIC) values and goodness of fit tests generated by the program, as well as by visually judging the fit of the proposed model to the observed distance data close to the transect line. The best possible model was selected based on the above considerations. The estimates of the following parameters were generated: encounter rate (n/L), cluster density (Ds), cluster size (Y), and animal density (Ď).

Capture–recapture method

The capture–recapture method was based on individually identified elephants that can be easily identified in the field. All the elephants were photographed systematically and named. We used two different methods to estimate the population. First, we used the simple Lincoln–Peterson estimator (Otis et al., 1978) as this allows the data to be directly compared with the study done in the mid-1980s, which also used this method (Daniel et al., 1987). We also used a more robust sampling design (capture–recapture methods) that allowed using both open (POPAN model; Schwaz, Arnason, 1996) population model that does not assume geographically closed population and closed population model (Otis et al., 1978; Pollock, 1982) for estimating the male population in the sampling area. Capture–recapture method, adopted to estimate male Asian elephant population parameters in the adjoining Nagarahole–Bandipur national parks (Goswami et al., 2007), is widely acknowledged as a robust method to assess Asian elephant populations (de Silva et al., 2011; Gupta et al., 2017; Goswami et al., 2019).

Elephant surveys were carried out for 12 months, from May 2007 to April 2008. The sampling was done in a sub-section of MTR in 17 roads that cover an effective sampling area of 160 km^2. The survey routes consisted of 128.5 km and were sampled twice per month. The park area is bounded by the Moyar Gorge on the northeastern side and human settlements on the southwestern side, both of which act as a physical barrier for elephant movement. The forest connectivity is there in the eastern part of survey area to the Bandipur tiger reserve hence the free movement of elephants is possible in the survey area during sampling period.

Demography

The age–sex composition was determined based on the direct sighting of elephants in the field. Data were collected systematically across the entire study area to ensure that all the vegetation strata were well sampled. We classified the elephants into various age–sex categories based on relative height and morphological characteristics (Mckay 1973; Daniel et al., 1987). Younger elephants (<15 years) were classified by comparing their height to the oldest adult female in the group. Elephants were placed in broad age groups: calves (<1 year), juvenile (1–5 years), sub-adults (5–15 years), and adults (for females ≥16 years and for males ≥20 years). The differentially structured age classification was used for comparison with earlier studies (Daniel et al., 1987; Baskaran, Desai, 2000). Inter-calving interval was estimated based on the difference in ages of the last two calves of a female (especially a female with a newborn calf that still has the older calf along).

Results

Population size and density estimates

Estimated elephant density based on distance sampling methods varied across the season, with higher density recorded during the dry season (3.3 elephants/km^2) than the wet season (1.8 elephants/km^2; Table 1). The mean group size was higher during the wet season (4.3) than the dry season (3.6–3.8), whereas group density was less in the wet season (0.43) than the dry season (0.8).

A total of 27 male elephants were individually identified in MTR, and they consisted of both adults and sub-adults. These identified elephants were resighted on 52 occasions. To determine the population density, we used the method reported in an earlier study. The coarse recapture probability was calculated as 1.926 (i.e., 52 recaptures/27 individuals = 1.926).

Table 1. Estimated elephant population group density, group size, and individual density in Mudumalai Tiger Reserve.

Season	Effort (km)	Model	ESW (m)	DS ± SE (95% CI)	E(S) ± SE (95% CI)	D ± SE (95% CI)	% CV
Dry 2007 (*n* = 20)	225.5	Half normal + cosine	51.9 ± 7.72	0.85 ± 0.32 (0.41–1.77)	3.82 ± 0.77 (2.51–5.82)	3.27 ± 1.39 (1.44–7.38)	42.76
Wet 2007 (*n* = 12)	140.0	Half normal+ cosine	107.3 ± 26.60	0.43 ± 0.196 (0.18–1.04)	4.26 ± 1.16 (2.36–7.72)	1.83 ± 0.97 (0.67–4.99)	52.97
Dry 2008 (*n* = 31)	286.0	Half normal+ cosine	60.8 ± 7.23	0.89 ± 0.25 (0.51–1.55)	3.64 ± 0.52 (2.73–4.86)	3.25 ± 1.02 (1.76–5.89)	31.42

Notes: ESW – estimated strip width; DS – mean group density; E(S) – mean group size; D – density; SE –standard error; CI – 95% confidence interval, lower and upper limits; CV- Coefficient of variation .

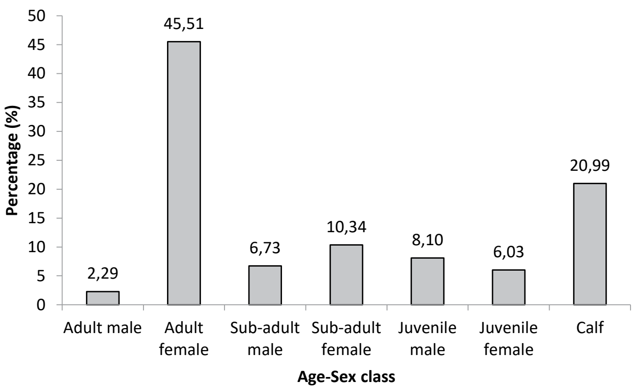

Fig. 2. Age-sex structure of the elephant population in Mudumalai Tiger Reserve (*n* = 479 groups).

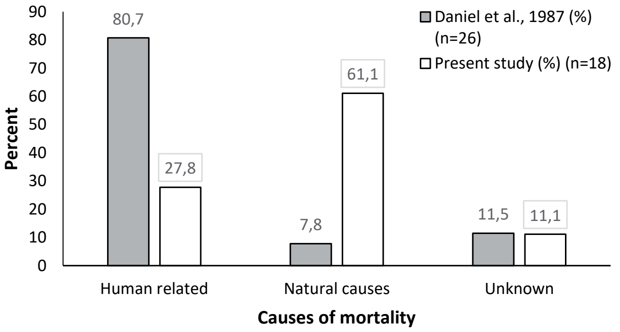

Fig. 3. Causes of elephant mortality in Mudumalai Tiger Reserve and adjoining RF areas during the study period.

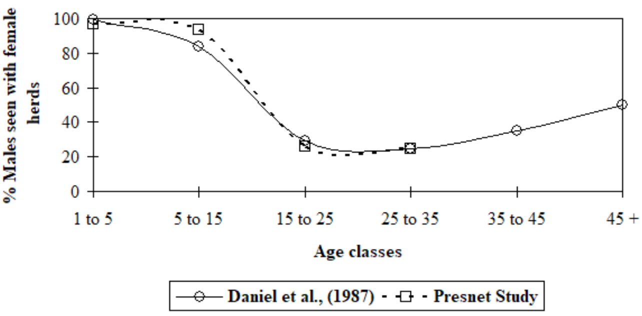

Fig. 4. Male association with female herds in Mudumalai Tiger Reserve in the past study and present study.

Table 2. Estimated male elephant population based on capture–recapture (closed population estimate).

Model[a]	Mean ± SE	Lower	Upper	AIC
M_t	33.0 ± 3.53	29.06	44.51	333.5
M_{tb}	28.3 ± 2.25	27.14	39.96	334.6
M_b	27.5 ± 0.84	27.04	31.89	346.5
M_0	34.0 ± 3.91	29.52	46.44	354.4

Notes: [a]M_0 – null model; M_t – time variate; M_b – behavioral model; M_{tb} – time and behavioral model.

The estimated population of the male elephants based on closed capture–recapture was 33.3 ± 3.53, the time depended model was selected than other models with the lowest AIC values (Table 2). The male elephant population estimated by the POPAN model was 47.04 ± 8.78. The test for population closure indicated a closed population ($z = -999$, $p > 0.05$) based on Otis et al. (1978).

A total of 187 groups were sighted during the sampling period; this would imply that there are 97.1 individual groups, assuming the same recapture probability for males (i.e., 187 groups/1.926 recapture probability = 97.09). The mean group size was 5.33 elephants, and this would imply that the groups account for 518 elephants. So, the total number of elephants for the area would be 545, that is, 518 elephants in groups and 27 males. This gives a crude density of 3.4 elephants/km^2 (i.e., 545/160 km^2).

Demography and sex ratio

A total of 516 groups were sighted during the study period. All individuals in 479 groups were completely classified into different age–sex classes. Adult females constituted 45.5% of observations, compared to 2.29% adult males (Fig. 2). Sub-adults, juveniles, and calves constituted 17.1, 14.1, and 21%, respectively. The adult male to adult female ratio was 1:20. Among adult males, the ratio of makhnas (tuskless males) to tuskers was 1:4, which implies that makhnas make up 20% of the male population.

Comparison of the sex ratios for different age classes in MTR showed improvement in the number of males relative to 1999–2000 period (Table 3). The adult male population showed marginal improvement, but the bulk of the adult class was made up of females, whose population continued to grow rapidly in the absence of any major threat to this age class.

Mortality

Daniel et al. (1987) had reported that humans were responsible for 80.7% of deaths in the present study area. However, in the present study, human-related mortality of elephants was 27.8% (Fig. 3). The major percent (61%) of mortality was due to natural causes like disease, injuries, and predation by tiger (two calves). There were sex-based changes in mortalities that had occurred over time; while adult and sub-adult male mortalities were the highest (83%) in the earlier study period, adult female mortalities were the highest (54.5%) during the present study (Table 4).

Association of males with female herds

The association of male elephants in the female herds did not show any significant change from the earlier study (Fig. 4) by Daniel et al. (1987). No associations between males and female herds were found in the 35 years and above age classes, as there are no males in these age classes in MTR at present.

Discussion

Population density

Estimated density of elephants based on capture–recapture and distance sampling indicated that population density increased in the study area. Baskaran and Desai (2000) had estimated a popula-

Table 3. Age structure and sex ratio of the elephant population of Mudumalai Tiger Reserve between 1987 to 2008.

Age class	1985–1987 (Daniel et al., 1987) (n = 1449)		1999–2000 (Baskaran, Desai, 2000) (n = 586)		Dec 2006–May 2008 (Present study) (n = 479)	
	Age structure (%)	Sex ratio	Age structure (%)	Sex ratio	Age structure (%)	Sex ratio
Adults	39.3	1:4.9	41.5	1:29.4	48.47	(1:20)
Sub-adults	21.1	1:1.1	24.1	1:2.9	16.56	1:1.5
Juveniles	25.8	1:0.8	24.9	1:1.5	14.07	1:07
Calves	13.8	1:1[a]	9.5	1:1*	20.90	1:1[a]

Note: [a]Calves' sex ratio assumed to be equal at birth.

tion density of 2.4 (±0.11) for the year 1999–2000. Earlier studies by Daniel et al. (1987) indicated a much lower population density (one elephant/km^2) for the same area. But this earlier study used a coarse ratio method (known:unknown) to estimate the population size. However, Baskaran and Desai (2000) argued that despite the differences in methods used, there is increase in the population size.

Despite poaching reducing the number of males, the elephant population in the study area is increasing. Daniel et al. (1987) had pointed to this very fact in their study and stated that despite the high levels of poaching (male biased), the population was growing, and this was a cause for worry, given that the density was a little over 1 elephant/km^2. Sivaganesan (1991) and Sivaganesan and Sathyanarayana (1995) had indicated that the preferred tree species of elephants were declining rapidly and one of the main causes for the decline of adult trees was feeding by elephants. While this would have been an indicator for the local population, other confounding factors like rainfall, fires (Suresh et al., 2010), and other herbivores (deer) suppressing regeneration were not studied, and therefore, the decline of these tree species could not be attributed entirely to elephants.

Density estimates by capture–recapture method

If these densities are extrapolated to the park, it gives a population that is three times the size of the population estimated in 1987 (Daniel et al., 1987) using a similar method but covering the entire protected area. There can be little doubt that the population has grown significantly in the last two decades, even if we assume that there was some underestimation in the past. What was apparent was that resighting (recaptures) was relatively poor in this study relative to that done in Nagarahole (Goswami et al., 2007). This would indicate that some sites are suitable for such studies while others are less so. The effort needed to get good sample sizes in less-suitable areas would be high, so this method cannot be recommended for all areas even if elephant densities are high. This is slightly higher than the density estimated using other methods, but this could be because roads by and large are located in good terrain (also suitable for elephants) and close to water sources (attracts elephants) and some of the roads are especially designed for viewing wildlife (biased toward high-density areas).

Demography

Comparison of the age structure of MTR with earlier data showed that the adult population has increased significantly due to an in-

Table 4. Changes in adult and sub-adult male and adult female mortalities in Mudumalai Tiger Reserve and adjoining RF areas.

Age–sex classes	Daniel et al. (1987) (%) (n = 26)	Present study (%) (n = 11)
Adults and sub-adult males	83	45.5
Adult females	17	54.5

crease in adult females, as shown by Desai and Baskaran (2000) (Table 1). The decline in the juvenile class could be either due to poor recruitment in the past several years or reduced breeding in the past few years. Desai and Baskaran (2000) had recorded only 9.5% calves in the population, but cautioned that this could be due to natural reasons as more females are likely to calve in 1 year and fewer are likely to calve in the subsequent years. Similarly, the high proportion of calves (20.9%) seen in the present study could be an indicator of a normal cycle of high and low births based on the number of adult females that are available for breeding in any given year. However, the data indicates that we need to monitor systematically and regularly to detect any signs of a decline in breeding. The sub-adult class too has declined relative to the other two studies, and it could also indicate lower recruitment and more animals moving into the adult age class. However, with a decreased juvenile age class and the sub-adult age class, there is a strong probability that breeding was affected when the adult male:female sex ratio declined to 1:29 in 2000. It could also imply that the increased population results in increased calf and juvenile mortality due to increased competition for resources and it is affecting recruitment. There is a clear need to monitor the population structure closely to ascertain changes and monitor trends, so that we can better manage the population and address long-term conservation needs.

Sex ratio

Comparison of the sex ratios for different age classes in MTR showed improvement in male numbers relative to 1999–2000 period (Table 2). The adult male population showed marginal improvement, but the bulk of the adult class was made up of females whose population continued to grow rapidly in the absence of any major threat to this age class. This was also highlighted by Desai and Baskaran (2000). Change in the adult sex ratios of this scale

(1:29 to 1:20) can be brought about by the addition of only a few males being recruited from the sub-adult class. This would be normal, given the 8-year gap between the 2000 study and the 2008 (present) study. Given the fact that poaching in the region has not been reduced and there are also deaths of males due to human-elephant conflict (retaliatory killings) and natural mortality, the adult male numbers have not changed significantly, clearly indicating a need for improved vigilance and increased anti-poaching efforts, as also efforts to eliminate retaliatory killings. Park managers need to realize that mortality in the non-PA areas also affects their populations. Elephants have large home ranges, which extend well outside PA and into RF areas that have fewer resources for protection and also have different management goals and priorities. This problem was highlighted by Desai (1991), and it needs to be addressed urgently through improved coordination between PAs and RFs and increased support to RF areas. There was a significant improvement in the sex ratio of the sub-adult age class, but these changes can be expected to occur fast with improvement in protection, as there would be rapid recruitment from the juvenile age class. The juvenile class too showed an improvement in the sex ratio and was comparable to the ratios obtained in 1987.

Impact of poaching

Daniel et al. (1987) had reported that human was responsible for 80.7% of deaths in the present study area. Similarly, 88% of mortality was due to train collision and was human mediated in Rajaji National Park (Williams et al., 2007). However, in the present study, human-related mortality of elephants was 27.8% (Fig. 3). The major percent (61%) of mortality was due to natural causes like disease, injuries, and predation by tiger (two calves). Sukumar (1985) estimated that humans were responsible for 20% of female elephant deaths and 65% of male elephant deaths in South India, so there has been a general decline in man-mediated mortality of elephants.

There were sex-based changes in mortalities that have occurred over time; while adult and sub-adult male mortalities were the highest (83%) in the earlier study period, adult female mortalities were the highest (54.5%) in the present study. This shift is likely due to the reduced number of males and consequently, a reduction in poaching. Poaching has declined over time in terms of the number of males killed. The reason for this is twofold‑first, there has been an increased anti-poaching effort that has made it more difficult to poach; second, there has been a reduction in the number of adult males, and also the tusk sizes available today (in other age classes) do not make it lucrative to establish and run poaching networks. The poaching that takes place is largely opportunistic and not organized as in the past, where dedicated poaching gangs operated. However, males are still being killed at higher rates than they are present in the population. Considering this, it then becomes very important that efforts to contain elephant poaching and also retaliatory killings (HEC related) be minimized. Lower male mortality numbers should not create a sense of complacency that could allow organized poaching to return when male numbers are up.

Breeding

Daniel et al. (1987) suggested that skewed sex ratios even in the region of 1:5 would not affect breeding because males are polygamous and not all females come into estrus in any given year. Given the inter-calving interval of approximately 5 years, it would mean that an average of 20% of the females would breed in any given year. This would mean an effective male:female sex ratio of 1:1 even when the actual sex ratio is 1:5 in the population. Although the study by Daniel et al. (1987) did indicate that there are years with peaks and years with low births, it is likely that breeding would not get affected at even wider sex ratios. It is difficult to estimate at what ratio breeding would be affected, but the present poor representation of sub-adults and juveniles (Table 4) in the population may indicate that breeding has been affected. Adult male:female ratios of 1:29 estimated by Baskaran and Desai (2000) appear to have resulted in poor and the low proportion of calves (9.5%) in their study. But, lower proportion of calves in the population might also due to a naturally low birth at the time of sampling. Thus, considering only the lower proportion of sub-adults and juveniles indicated breeding has been affected in the past.

Earlier in the 1980s, most matings were done by the large adult males which were over 30 years (Desai, unpublished data) and were the only ones that had extended musth periods. But in the current study, males below 20 years showed clear signs of musth (heavy temporal flows and swollen temporal glands) and sustained it for longer. In the 1980s, males in this age class only showed mild signs of musth with no temporal swelling and only a small fine small flow of temporal fluid and musth sustained for a week or so. This change shows that younger males that could never mate when the older males were alive were not taking on the role of breeding. Males as young as 10–15 years have been seen in musth. Such a shift in breeding might help overcome the problem of poaching of larger males, but now the poaching has shifted to these smaller males and there are no males over 40 years of age in the population. This sustained decline of males would ultimately result in eliminating the genetic diversity of the male population as fewer males continue to breed.

There appears to be no significant change in the male–female association from the earlier study by Daniel et al. (1987). The decline in male numbers does not appear to have changed their behavioral pattern in terms of their association with females. No associations between males and female herds were found in the 35 years and above age classes, as there are no males in these age classes in MTR at present.

Makhna to tusker ratios

Among adult males, the ratio of Makhnas (tuskless males) to tuskers was 1:4, which implies that makhnas make up 20% of the male population. Williams et al. (2007) estimated that makhnas constitute 10% of adult males in Rajaji National Park. Whereas in Sri Lanka, 90% of the sub-adult and adult bulls are makhnas (Katugaha et al., 1999). Daniel et al. (1987) had estimated in their study that makhnas made up approximately 13% of the population. In contrast to these habitats, Goswami et al. (2019) estimated a tusker to makhna ratio of 1.2:1 in Kaziranga National Park, suggesting that makhnas comprised ~45% of the male population. While the proportion of makhnas in the male population appears to have almost doubled, the actual change is significantly greater as the tusker population was already severely depleted by poaching as reported in the study of Daniel et al. (1987). This would mean that the original proportion of makhnas in the population would have been far less than the 13% estimated by them. While the continued decline in tusker population would account for a significant part of the change in the proportion of makhnas, it would not account for all the changes as we are now dealing with a new generation of males. When all the large adult tuskers were poached off in the 1980s and early 1990s, the adult makhnas were also eliminated in the 1990s and in the early part of 2000s due to HEC-related killing and one elephant was even captured due to HEC. Thus, we are dealing with a new generation of males and the increase in the proportion of makhnas would be due to an actual increase in their numbers, rather than other factors alone. But when the bulk of the large tuskers was eliminated from the population by the 1990s, the large adult makhnas would have monopolized mating, and this could account for some of the increase in the population of makhnas.

Acknowledgements

We thank Tamil Nadu Forest Department, Tamil Nadu for permitting us to undertake this study. We thank the US Fish and Wildlife Service for providing funding support (AAA No. 98210-6-G113). We thank the former director and honorary secretary of Bombay Natural History Society. We thank all the field staff and our field trackers and elephant mahout for their support during the study. We thank Mr. Ajay A Desai for his excellent mentorship.

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