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Seasonal Crop Raiding of Fruit Trees by Asian Elephants: An Insight into Foraging Preferences from Croplands Abutting Bannerghatta National Park, Bengaluru, Karnataka, India

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Authors' contributions

This work was carried out in collaboration between all authors. Author MB carried out the field work, managed the literature searches, performed statistical analysis and wrote the first draft of the manuscript. Author AG assisted in performing statistical analysis and edited the manuscript. Author AK laid the objectives, designed the study and protocol and critically reviewed the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study was undertaken to evaluate factors which potentially influence crop depredation by Asian elephants during the non-cropping season. The study was conducted in a 2.5 km zone abutting Bannerghatta Wildlife Range of Bannerghatta National Park, Karnataka. Three fruit trees which are commonly raided by elephants, namely jackfruit (*Artocarpus heterophyllus)*, mango (*Mangifera indica*) and tamarind (*Tamarindus indica*) were selected for the study. The convenient sampling approach was adopted to map individual trees of the three species between May and July 2015.

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Factors such as the phenological stage, the parts of the tree foraged, the distance from the Park boundary and the crop clustering pattern were recorded. Among the 1368 mapped fruit trees, only 4.31% (n = 59) of the trees were found foraged on. However, 79.66% of the damage occurred in trees that were fruiting. There also seemed to be a preference in fruits foraged; *A. heterophyllus* had the highest damage (8.84%), followed by *T. indica* (4.20%) and *M. indica* (3.66%), and the preference ratios for the three species were estimated to be 2.05, 0.97 and 0.85, respectively. The analysis showed that the spatial foraging pattern was also species dependent, with damage in *A. heterophyllus* and *M. indica* recorded at distances more than one km from the Park unlike in the case of *T. indica*. Refuge cover availability and forage quantity measured through clustering pattern, was not found to positively increase foraging preference. It was also observed that damage in fruiting *M. indica* were more common in areas which contained both *A. heterophyllus* and *T. indica* within 100 m, than areas which had either none or only one of the species present. Spatial analysis revealed a concentration of foraging in the north-western and south-eastern portions of the National Park. Results obtained in the study aided in identifying the indicative factors which influence the crop foraging pattern during the non-cropping season. A detailed long-term study on the foraging ecology of elephants in other human-dominated regions will help strategize effective human-elephant conflict mitigation measures.

Keywords: Asian elephant; crop raiding; human-elephant conflict; Bannerghatta National Park.

ACRONYM

WLR : Wildlife Range

1. INTRODUCTION

Crop raiding is stated to be a necessity for elephants in some cases [1] and a foraging strategy in others, which offer nutrition that is either not substantiated or are equivalent to the wild natural fodder [2,3]. Alternatively, crop raiding also occurs due to assumed high palatability [4,5] and other benefits for elephants including fewer parasites [6] compared to elephants which do not crop raid.

Despite the discerned advantages, the behaviour of crop raiding is an acquired practice and may not be adopted by all individuals in a population [1] abutting crop fields. The origin of crop raiding behaviour has been predicted to be either opportunistic through direct encounters or during dispersal, or obligatory when actively sought after [7]. Crop depredation poses numerous threats to the concerned individuals [7] and often renders them susceptible to retaliatory killings [8,9]. Elephants may recognize the potential risks associated with traversing or foraging within human-dominated realms [10] and thus, evidence of adaptations has been recorded.

Some adaptations are temporal where incidences of raiding have occurred predominantly during the night [11,12] and some are spatial where crop damage has been found to be negatively correlated to the distance from forested areas [13,14]. Further studies suggest that consumption per unit time could be a possible factor in determining the phenological status during which crop raids occur [11].

Crop raiding is, thus, dependent on certain factors. Comprehension of the foraging ecology and behaviour exhibited during foraging outside natural forested habitats may be one of the key components that may aid in developing effective mitigation measures [13].

In this regard, the current study was an attempt to identify some key factors which may influence crop raiding during the non-cropping season in agricultural lands abutting Bannerghatta National Park. This study focused on primarily assessing how spatial positioning, clustering and fruiting of trees influence foraging pattern in elephants outside natural forested regions.

2. METHODOLOGY

2.1 Study Area

Bannerghatta National Park (BNP) (12° 20’-50’N, 77° 27’-38’ E), encompassing an area of 260 km^2, lies at the most northern tip of the Eastern Ghats in the State of Karnataka (Fig. 1). BNP is predominantly a tropical dry deciduous forest with patches of mixed deciduous vegetation. It contains a minimum diversity of 128 tree species including *Anogeissus latifolia*, *Acacia chundra* and *Cedrela toona* [15]. BNP supports a mean density of 1.84 elephants/km^2 [16] and elephant habitat usage signs have been reported to occur uniformly throughout the year, based upon surveys conducted between 2005 and 2008 [17].

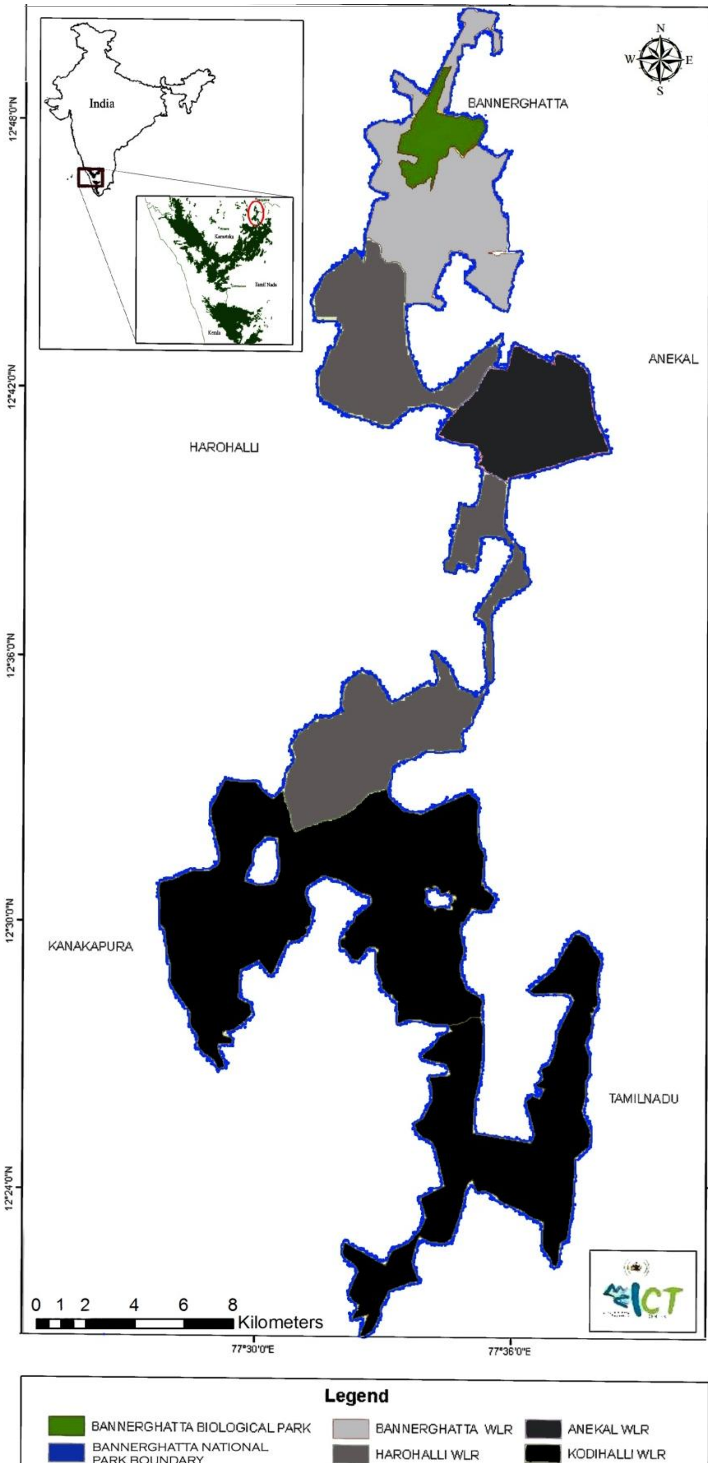

Fig. 1. Bannerghatta National Park
(Inset: Position of Bannerghatta National Park in the Nilgiri-Eastern Ghat landscape)

A land-use map of the 7.5 km buffer zone abutting Bannerghatta National Park shows that 21.3% is occupied by horticultural crops, 11.8% by forested land and 42.5% by agricultural land

[17]. As a consequence, there have been many occurrences of human-elephant conflict on the fringes of BNP, especially crop depredation. Crop raiding has been reported to occur throughout the year with peak conflicts occurring between October and January. A collation of compensation claims within the villages abutting BNP revealed that a minimum of 37 types of crops were raided by elephants. During the off-peak conflict months in May and June, 17 agricultural and tree crops were reported to be damaged by elephants [17].

The current study was conducted in the designated 2.5 km buffer zone abutting Bannerghatta Wildlife Range, one of the four administrative ranges of BNP. The objective of the study was to understand the factors which influence crop raiding during the non-cropping season. Bannerghatta Wildlife Range (37.18 km^2, 14.30% of BNP) had the highest number of elephant feeding signs recorded among the three Ranges (Bannerghatta, Anekal and Harohalli) [17] suggesting the availability of natural fodder within the forested habitats. Being the northern-most Range, there have also been reports suggesting the seasonal movement of bulls between BNP and Savandurga State Forest (12° 51'-57' N, 77° 16'-20' E) through the northern portions of BNP [18] with presumably high probability of crop encounters. The vegetation cover map reveals the presence of forest patches extending in both a north-west direction and a south-east direction (Fig. 2) [19].

2.2 Study Design

Three fruit trees were chosen, namely jackfruit (*Artocarpus heterophyllus),* mango (*Mangifera indica*) and tamarind (*Tamarindus indica*), to identify the possible factors determining the foraging preferences of elephants in human-dominated regions during the period 26th May and 3rd July 2015. The selected trees overlap with the fruits naturally consumed in the wild in dry deciduous forest habitats during the dry season (January to April) and the first wet season (May to August) [20]. The selection aided in eliminating the need to assess the nutritional content as a factor for crop raiding. The survey period aided in obtaining assumed increased possibility of tree foraging through (i) not being a peak cropping season [17] and (ii) being the peak fruiting season for *A. heterophyllus* and *M. indica*. Besides, the migration of bulls between Savandurga State Forest and BNP were observed to occur predominantly in the second wet season (September to December), often during *musth* (Avinash Krishnan, A Rocha India, Bengaluru, personal communication, 2015). Hence, the chosen study period also

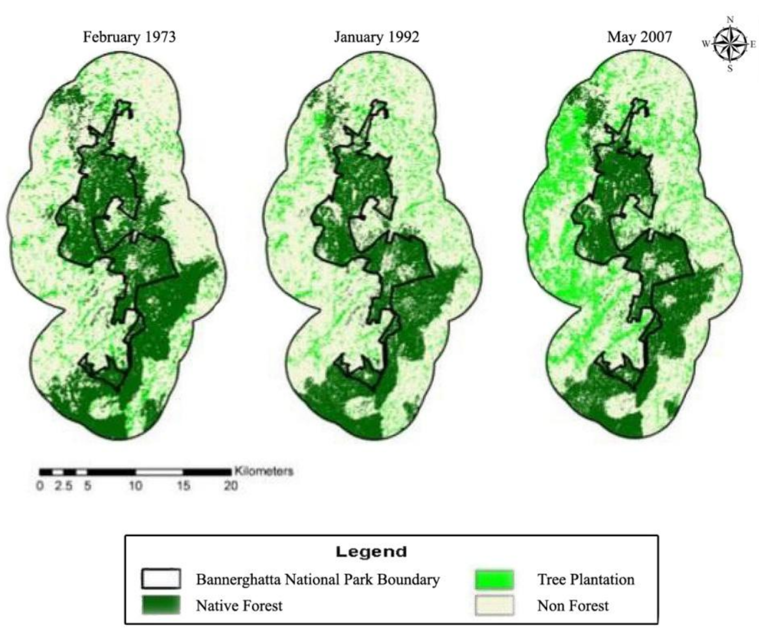

Fig. 2. Periodic vegetation cover map of Bannerghatta National Park
**Obtained from [19]*

attempted to clarify the influence of migration on the foraging pattern considering May to July to be possibly non-migratory months. A convenience sampling approach was adopted through foot survey to map the selected fruit trees within the 2.5 km community land buffer on the boundaries of Bannerghatta Wildlife Range. Mapped trees were classified into fruiting and non-fruiting to assess the influence of fruiting on foraging, considering that fruits determine the movement of wild elephants [21]. The mapped trees were classified into isolated trees, scattered trees and plantations to identify the relationship of clustering on the intensity of damage. This was based on the assumption that clustering in cultivated crops will provide higher gains and better refuge cover for elephants. Trees were considered to be isolated if no other trees of the same species were found within a 50 m radii and, were marked as scattered if 2-10 trees were located less than 50 m apart. Trees that were classified as plantations had more than 10 trees with less than 50 m apart. Since data exists on the availability and usage of wild fodder within the adjoining wildlife range throughout the year [17], obligatory foraging as a reason for crop depredation was assumed to be less probable in this study. In that regard, parameters such as the GPS co-ordinates and the distance from the protected area were recorded to evaluate the presence of any probable spatial foraging pattern. Supplementary data collected included the parts of tree consumed/damaged, to attempt gauging the economic losses incurred from the damage inflicted on the fruit trees. A feeding ecology report revealed that six per cent of the trees were felled in the wild during consumption [22] and may cause tree mortality apart from the temporary loss in the crop yield to the cultivator. Adjoining village names were noted to enable easy referencing. The data collected was analyzed by sorting and filtering using Excel. Preference ratio for the three species were estimated following [23] as described in [24]. Significance was tested using the Pearson χ^2 Test or the Fisher Exact Test with $P<0.05$.

3. RESULTS

During the study period, a total of 1368 fruit trees comprising jackfruit (*A. heterophyllus*), mango (*M. indica*) and tamarind (*T. indica*) were mapped on the western and eastern borders of Bannerghatta Wildlife Range within the 2.5 km zone (Fig. 3). The number of fruiting and non-fruiting trees mapped are given in the table (Table 1). Despite the fruiting season for *M. indica* being April - July, the high occurrence of non-fruiting trees (78.54%) was attributed to the unseasonal rainfall which occurred during the first week of March 2015 [25].

3.1 Foraging Damage of the Different Fruit Tree Species

3.1.1 *A. heterophyllus* trees

A total of 13 damaged trees were recorded, of which 92.30% (n = 12) of the damage/foraging had occurred in fruiting trees. The damaged non-fruiting tree lies at a distance of 0.04 km from scattered fruiting *M. indica* trees that was also recorded foraged. Among the damaged fruiting trees, eight trees were marked as isolated and four as scattered; no *A. heterophyllus* plantations were encountered during the study. There was a significant difference in the damage between isolated and scattered trees (P = .01). *A. heterophyllus* trees in fruiting stages were found to be present up to two km (min = 0 km) from the park boundary (PB) and the damage occurred in trees at a maximum distance of two km (min = 0.08 km).

3.1.2 *M. indica* trees

Among the damage (n = 36) that had occurred, 75% (n = 27) of them were in fruiting trees. Damage in non-fruiting trees occurred in areas close to foraged *A. heterophyllus* (0.30 km, n = 2) and *T. indica* (0.01 km, n = 3) and in areas closer to the PB (0.14 km, n = 4). Ninety four per cent (n = 34) of the damage occurred in trees

Table 1. Composition of fruit trees mapped during the study period

S.No.	Species of fruit tree	Total number of trees mapped	Number of fruiting trees	Number of non-fruiting trees
1	*Artocarpus heterophyllus*	147	74 (50.34%)	73
2	*Mangifera indica*	983	211 (21.46%)	772
3	*Tamarindus indica*	238	150 (63.02%)	88
	Total	**1368**	**435 (31.80%)**	**933**

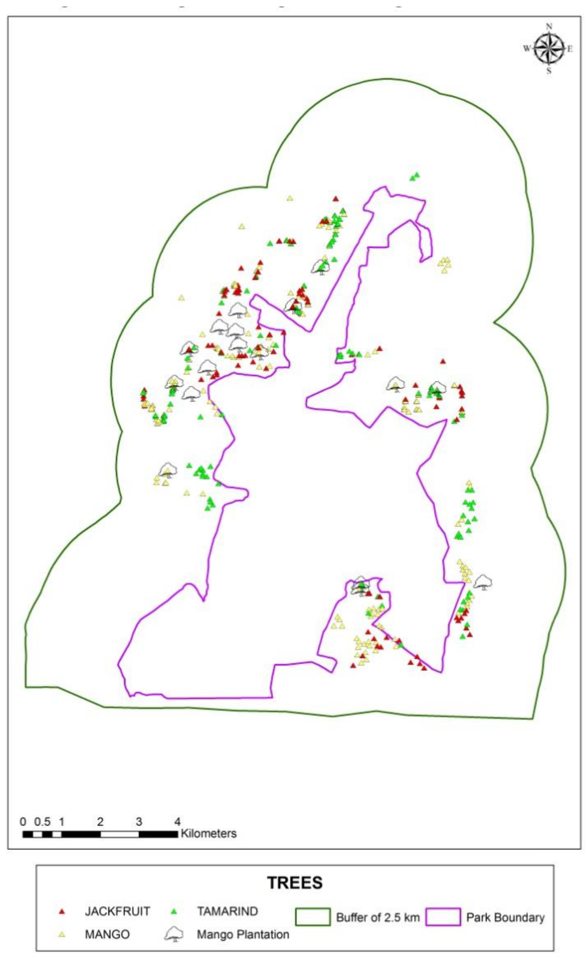

Fig. 3. Spatial distribution of the fruit trees *A. heterophyllus, M. indica* and *T. indica* mapped during the study period

which were not isolated. None of the trees in regions classified as plantations (n = 21, N = 647 trees) were found damaged. There was no significant difference between the damage in isolated and non-isolated trees (scattered trees and plantation) (*P* = 1.00). *M. indica* trees were found distributed from 0 to 2.5 km from the PB. However, the damage in fruiting trees was found to range from 0.03 km to 2.5 km and the damage in non-fruiting trees was found to range from 0.14 km to 1.9 km.

3.1.3 *T. indica* trees

Ten of the trees mapped were found to have been damaged/foraged by elephants. All the damaged fruiting trees (n = 8) were found to be marked as scattered. Damage to the non-fruiting trees were in isolated trees in areas near damaged fruiting *A. heterophyllus* (0.002 km) and near the PB (0.06 km). There was no significant difference between the damage in isolated and non-isolated trees (*P* = .51). Though fruiting *T. indica* trees occurred from 0 to 2 km, the damage occurred within 0.2 km from the PB (min = 0.02 km) in 80% (n = 8) of the damage and at 0.57 km and 1 km in the other two records.

Comparative results obtained for foraging preferences within the three fruit trees are represented in the figures (Figs. 4 and 5).

3.2 Foraging Preferences between the Fruit Trees

During the study period, damage occurred in 4.31% (n = 59) of the total trees mapped. Among the three selected trees, *A. heterophyllus* had the highest damage (8.84%, n = 13), followed by

T. indica (4.20%, n = 10) and *M. indica* (3.66%, n = 36). Preference ratio for *A. heterophyllus, M. indica* and *T. indica* were calculated to be 2.05, 0.85 and 0.97, respectively (Table 2).

3.3 Foraging Preferences Related to Fruit Tree Spatial Patterns

Among the trees mapped, 12.32% (n = 26) of fruiting *M. indica* were found in close proximity (distance between two species ≤ 100 m) to fruiting *A. heterophyllus*, 30.33% (n = 64) to fruiting *T. indica*, 16.12% (n = 34) to both *A. heterophyllus* and *T. indica*, and 41.23% (n = 87) to none. However, damage was recorded more in fruiting *M. indica* trees which were in close proximity to both *A. heterophyllus* and *T. indica* trees (51.85%), compared to only *A. heterophyllus* (11.11%), only *T. indica* (14.81%) and none (22.23%).

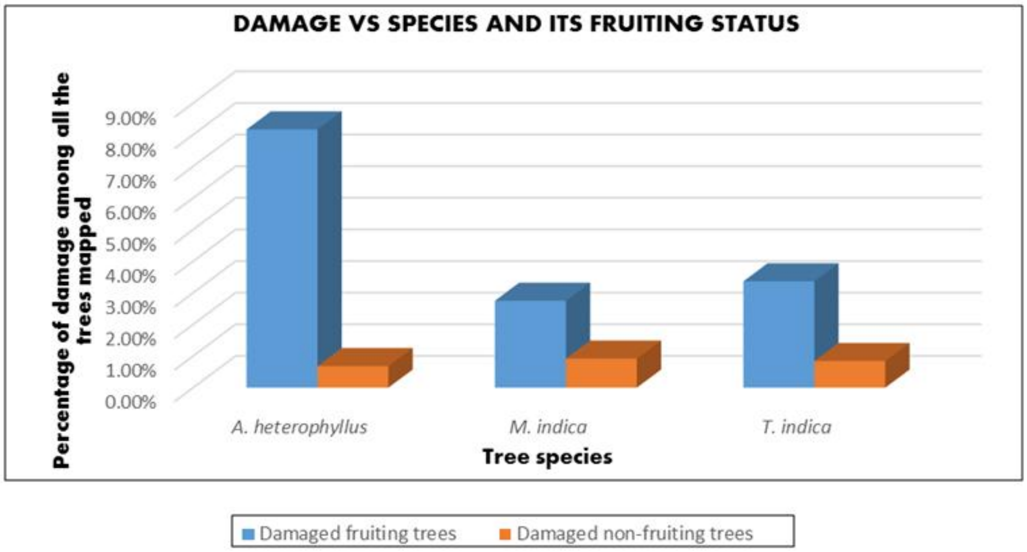

Fig. 4. Correlation graph representing relationship between fruit tree species and its fruiting status and the damage occurred

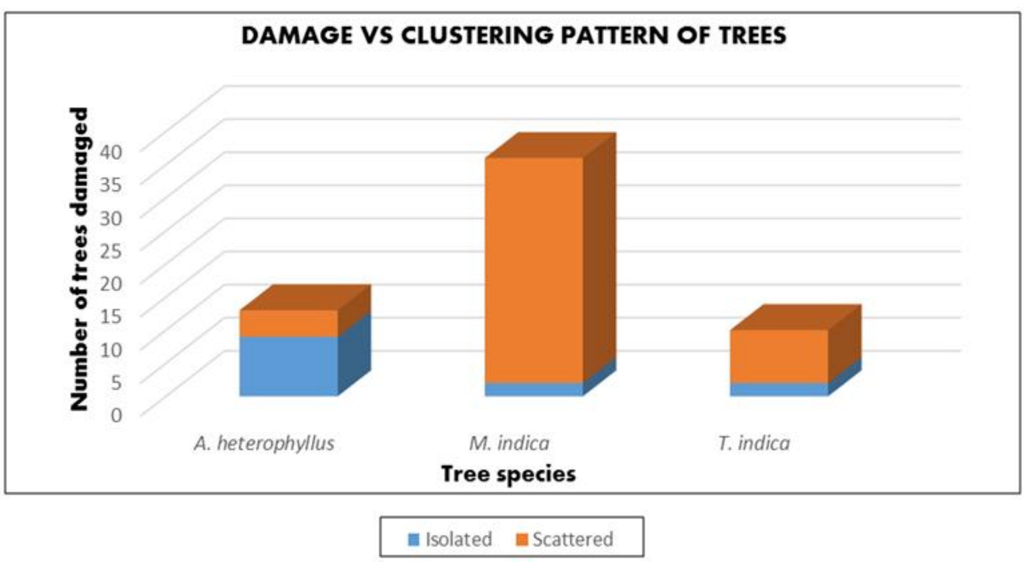

Fig. 5. Correlation graph representing relationship between clustering pattern of trees and the damage occurred

3.4 Spatial Distribution of Foraging in the Buffer Zone

The three selected fruit trees were found scattered in the 2.5 km buffer zone. However, clustering of damage which occurred showed a concentration in the north-western region and the south-eastern region (Fig. 6).

3.5 Economic Loss Incurred from Damage

Damage was inflicted on different parts to the fruit trees. Damage occurred in the fruits (81.35%), the branches (72.88%) and the leaves (37.28%). Four fruiting *M. indica* trees were found felled during the survey period, all of which were not isolated trees. The estimated economic loss was found to be highest in *A. heterophyllus* compared to *M. indica* and *T. indica* (Table 3).

4. DISCUSSION

From the results obtained, damage occurred predominantly in fruiting trees (79.66%, n = 47), as opposed to in non-fruiting trees (20.34%, n = 12). Consumption of non-fruiting trees were encountered largely in areas lying in close proximity to damaged fruit trees or in areas closer to the PB. This suggests that fruit trees, and their fruits, influence movement of elephants in human-dominated regions similar to the pattern obtained within natural forested regions [21]. The spatial foraging pattern was found to be species dependent and did not have a uniform inverse relationship with distance from the PB, as observed for *A. heterophyllus* and *M. indica* in croplands abutting Savandurga State Forest, Karnataka [14]. Damage occurred in areas more than one km from the PB in *A. heterophyllus* and *M. indica* unlike in the case of *T. indica.* Analyses also show that the damage in fruiting *M. indica* were recorded more in areas that contain both *A. heterophyllus* and *T. indica* within 100 m from *M. indica* trees, than areas that had none or only either of the species. Elephant foraging preferences estimated through preference ratios for the three species reveal a relatively higher foraging susceptibility for *A. heterophyllus* trees, compared to *T. indica* and *M. indica.* Fruits of *A. heterophyllus and T. indica* may, thus, be a potential attraction to wild elephants, making crop depredation in *M. indica* incidental than being sought after. The creation of a 100 m wide belt devoid of the two fruit tree species *A. heterophyllus* and *T. indica* around mango cultivations, may assist to decrease damage and felling of *M. indica* trees, given the current composition of trees exists. Nevertheless, understanding spatial positioning, phenological status, availability and usage of the three species within the adjoining wildlife range may provide further insight into the obtained pattern and may aid in strategizing the mitigation measures.

Table 2. Foraging preferences between fruit tree species estimated through preference ratio*

S.No.	Species of fruit tree	Availability of the species	Relative availability	Use of the species	Relative use	Preference ratio
1	*Artocarpus heterophyllus*	147	0.11	13	0.22	2.05
2	*Mangifera indica*	983	0.72	36	0.61	0.85
3	*Tamarindus indica*	238	0.17	10	0.17	0.97
	Total	**1368**		**59**		

**Following [23] as described in [24]*

Table 3. Estimated economic losses to fruit trees caused by the elephant-inflicted damage

S.No.	Species of fruit tree	Average yield/tree (kg)*	Market price (INR/kg)**	Total trees damaged (No.)	Loss of yield due to damage (kg)	Loss of income due to damage (INR)
1	*Artocarpus heterophyllus*	500	37	13	6500	2,40,500
2	*Mangifera indica*	30	30	36	1080	32,400
3	*Tamarindus indica*	17.5	51	10	175	8,925

**Values obtained from [17]*
***Values obtained from [25]*

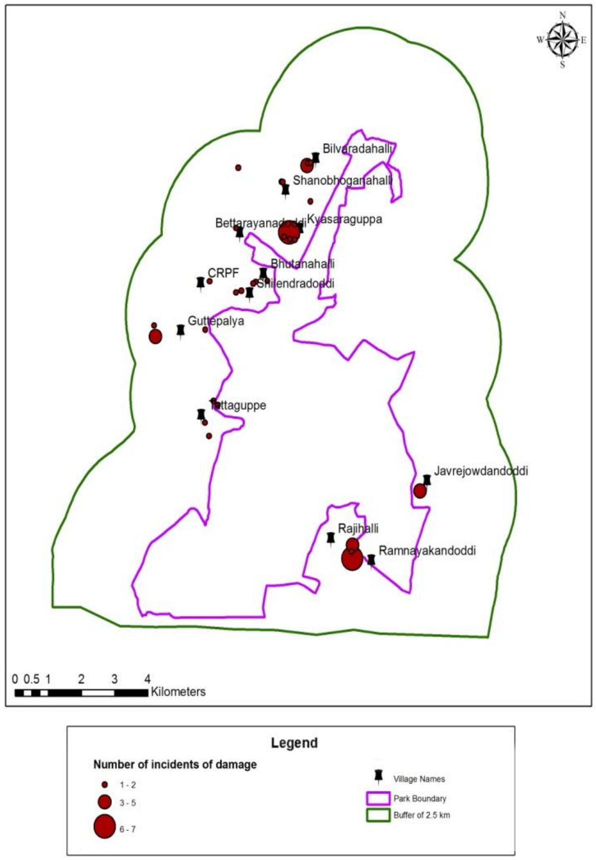

Fig. 6. Map showing cluster analysis of damage recorded during the study period

Another finding from this study was that the associated higher gain and high refuge cover availability with clustering of trees was not found to be positively proportional to damage. Similar results were reported in Yunnan Province, China [26], however, contrasting pattern was obtained in Ghana [27]. Though scattered trees were damaged, we recorded no instances of damage in plantations. This could be probably due to effective elephant mitigation measures being practiced for large farms. In both *T. indica* and *M. indica*, there was no significant difference in foraging based on clustering pattern, but isolated trees were predominantly damaged in the case of *A. heterophyllus*. The overall damage recorded in the three species during the study period can be considered to be less (4.31%), however, estimated total economic losses amount to INR 2,81,825. Damage recorded in *A. heterophyllus* being more in isolated trees may suggest a possibility of damaged trees being meant for personal consumption than for their economic value. Hence, loss in terms of *A. heterophyllus* damage may not affect the people economically but may contribute to the general fear for elephants, associated with crop raiding.

Mapping of damage recorded also shows that crop depredation was not uniformly spread in the human-dominated regions but were relatively concentrated in the north-western and south-eastern regions. These areas which were formerly forested in the early 1970s (Fig. 2) may have been migratory routes for elephants. Elephant encounters with potential forage may be opportunistic during migration or dispersal in this region, as one of the possibilities suggested by [7]. Reports of bulls migrating through the north-western region [18] coinciding with regions of damage recorded, may indicate a higher participation of bulls in crop raiding, similar to findings in other parts of southern India [28], compared to cow groups. A similar opinion was obtained during a questionnaire survey from farmers living along the fringes of Bannerghatta Wildlife Range, who reported significant participation of bulls in crop raiding in this study area [29]. Hence, we can propose that consideration of elephant migratory routes in planning settlements or community relocations may be a useful tool in minimizing crop depredation. The dependency of foraging pattern on migratory routes, however, may vary for other crops closer to the PB as reported by [27].

This study also shows that foraging in human-dominated regions occurs even during the non-migratory months. This finding supports the accounts of crop depredation being a recurring phenomenon [30] once the practice of foraging for the fruits of fruit trees has been acquired by the individuals. Identification of individual elephants foraging in these non-forested regions was beyond the scope of this study. Hence, a detailed systematic long-term mapping of the foraging patterns of individual elephants may aid in comprehending foraging behaviour and mitigate the conflicts appropriately.

5. CONCLUSIONS

From the study carried out, it was found that the distances at which foraging signs were encountered in relation to the park boundary were dependent on the species of fruit and the phenological stage of the trees, indicated by the obtained foraging preferences. Refuge cover availability and forage quantity was not found to increase susceptibility of foraging. However, the presence of two or more species of fruit trees in close proximity showed an increase in being foraged with regards to one another. On a spatial scale, the study revealed a significant concentration of foraging signs in the presumed elephant migratory routes; however, the results obtained were constrained by the short sampling period and the chosen crop types. A long-term study in this regard may aid in assessing the probable presence of annually recurring foraging patterns and the individuals contributing to human-elephant conflict in this landscape. Thus, a detailed research of the foraging ecology of the Asian elephant may increase the possibility of effectively mitigating the human-elephant conflict.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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