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Seed dispersal modes of tree species and their relation with altitudinal gradient from tropical forests of Eastern Ghats, India

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ABSTRACT

The present study reports the seed dispersal modes of tree species and their relationship with altitudinal gradient from six tropical forests of Eastern Ghats located in India. Anemochory, autochory and zoochory are the three major types of seed dispersal modes recognized for the 272 tree species recorded from a total of 120 0.5 ha area. The predominant dispersal mode is zoochory with 58% of the total tree abundance and 69% of total species richness, followed by autochory with 30% and 19%, and anemochory 12% and 12%, respectively. One way ANOVA revealed that the species richness as well as tree abundance of the three dispersal modes varied significantly across the six tropical forest sites. Regression analysis revealed that both the tree species richness and abundance of zoochory dispersal mode had positive relation with altitude of forest location, while, no such relation was observed for the other two dispersal modes. This study shows that the zoochory increases in species richness and tree abundance with increasing altitude. This may be attributed to high rainfall supporting ever-green forest types with high ratio of animal dispersed tree species in forests at high altitude. However, further studies on these aspects are warranted to draw a significant statement. The predomination of zoochory dispersal mode in this study is comparable with earlier studies in tropical forests elsewhere.

1. Introduction

The movement or distribution of seeds away from a parent tree is known as seed dispersal. It is one of the several ecological processes for the rich tropical biodiversity [1], including the habitat fragmentation [2]. Seed dispersal is aided by a variety of processes. The ability of tree species to spread seeds differs depending on the type of fruit they produce. Trees with fleshy berries, for example, are prone to animal dispersal, while samara, a dry fruit with a flattened wing of fibrous papery tissue, is prone to wind dispersal. The spatial trends can be influenced by seed dispersal modes. Plant seed dispersal is an essential though little-understood step in their life cycle [3]. Seed dispersal is critical to ecosystem systems at all sizes and stages of organization, but development is hampered by a scarcity of data [4].

Tropical forest tree populations are home to some of the world's most diverse communities. About the fact that maintaining diversity remains a major challenge in ecology [5], theoretical research has identified conspecific aggregation as a tool for reducing competitive exclusion and encouraging diversity [6]. Indeed, at scales ranging from a few meters to a few hundred meters, tropical forests display widespread accumulation of conspecific plants [7]. The cause of conspecific clustering needs to be

explored in depth [8], and it has been due to a variety of factors including patchy habitat heterogeneity [9], reduced seed dispersal [10], and neutral mechanisms that ignore species-specific traits [11]. The ability of tropical tree species to spread seeds varies. Limited dispersal is known to induce spatial accumulation in pioneer tree seeds and seedlings [12]. Apart from anecdotal evidence from studies restricted to a few plants, it is unclear if the spatial patterns created by limited dispersal continue beyond the seedling level [7]. The demographic loop that distinguishes observations of restricted seed dispersal from the long-term effects of dispersal for tree communities could be closed by establishing a connection between dispersal mechanisms and spatial trends at the community level [8]. Local dispersal-induced spatial aggregation could be enhanced by interactions with patchy environments [13] or shattered by density-dependent mortality from predation [14].

Tropical forests are without a doubt the most diverse habitat types in terms of tree species diversity, but scientists have long questioned the factors that drive such diversity [15]. Escape from seed predation near parent trees (Janzen & Connell hypothesis), high degree of aggregation on conspecific trees [9], and seed dispersal modes are some of the mechanisms [15].

To keep their offspring away from them to reduce competition

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between conspecifics that are closely related genetically, land plants have evolved a diverse set of reproductive characteristics and morphological adaptations. While this process of seed dispersal is brief in the life cycle of trees, it can have significant implications for later ecological processes regulating the fates of their seeds and juveniles, which can have important, long-term consequences for plant population dynamics, composition, and structure [16].

Seed dispersal connects the end of an adult plant's reproductive cycle to the beginning of a new one through offspring establishment. It is a significant driver of vegetation composition because it allows new areas to be colonized, preserves genetic diversity, and has indirect effects on succession, regeneration, and conservation [17]. Seed dispersal is needed, according to the Janzen-Connell hypothesis, to allow seeds and seedlings to avoid high density-dependent mortality caused by pathogens, seed predators, and/or herbivores in close proximity to the parent plant [14]. The seedlings that mature the furthest away from conspecific adults have an environmentally favorable condition [18]. Seeds as plant organs for reproduction, catastrophe recovery, and colonizing new areas must be suitably dispersed, and in long term, dispersal failure can lead to species extinction [19]. Seed dispersal is a key mechanism in the ecology and adaptation of plant species [20], and it occurs on a variety of temporal and spatial scales [21]. It is the most common stage at which plants travel in space in plant communities, resulting in the initial spatial pattern of new individuals [10]. Even so, the mechanism has enormous consequences at multiple organizational scales: for human life, development, and reproduction; for population and community composition, function, and dynamics; and for species longevity, evolution, and geographic spread [22].

Only a few studies have been conducted worldwide on seed dispersal [15–23]. Further, an extensive literature search has revealed that so far in Eastern Ghats of India, no study has been reported on seed dispersal patterns of trees with elevational gradients. Hence, to fill the knowledge gap, the present study was carried out to understand the seed dispersal modes of tree species and to find the influence of altitudinal gradient on the dynamics of seed dispersal mode distribution pattern in terms of species richness and abundance of trees.

2. Methodology

2.1. Study area

The current research was focused to report the patterns of seed dispersal modes of tree species from six tropical forest sites in the southern Eastern Ghats ($11^{\circ} 08.5' - 12^{\circ} 06.0' N$; $78^{\circ} 07.5' - 78^{\circ} 48.5' E$) of Tamil Nadu, India (Fig. 1). Namely, they are Bodamalai hills (BM), Chitteri hills (CH), Kalrayan hills (KA), Kolli hills (KO), Pachaimalai hills (PM), and Shervarayan hills (SH) (Fig. 1). These forest sites are made up of Charnockite masses, gneisses, and a number of metamorphic rock formations. In the six sites, the soil is red loamy and lateritic in nature. The mean annual temperature and rainfall for Salem station nearest to the study sites are $28.3^{\circ} C$ and 1058 mm, respectively.

2.2. Methods

The entire length of the southern Eastern Ghats was split into grids measuring $6.25 \text{ km} \times 6.25 \text{ km}$ using toposheets of scale 1:50,000. The

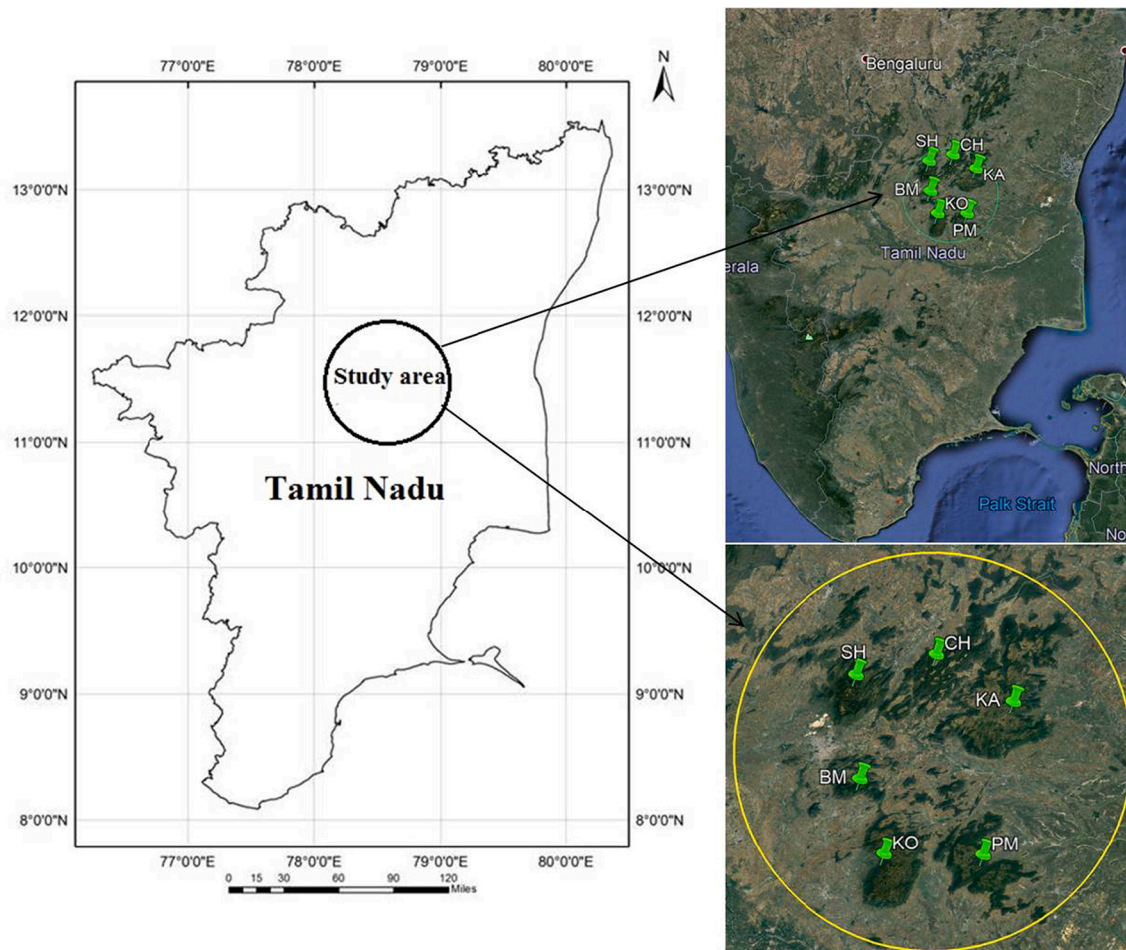


Fig. 1. Map showing the location of the six major hill forest fragments in Tamil Nadu, India.

six forest sites yielded a total of 120 grids, and all live trees with girth at breast height greater than 30 cm were counted in each grid from a belt transect of size 0.5 ha (5 m × 1 km). Each transect was divided into fifty 5 m × 20 m quadrats to make inventory simpler. This inventory protocol was designed as a nationwide effort to quantify plant resources of India, and the demography of these tropical forests sites is available in Pragasan & Parthasarathy [24]. Seed dispersal mode of tree species was determined based on its fruit traits and from available literature [15]. Tree species were categorized into different dispersal modes, and their species richness and abundance were determined.

2.3. Statistical analysis

One way analysis of variance (ANOVA) was used to test the level of significance in variation in species richness and abundance for the different dispersal modes across the six major tropical forest fragments of the Eastern Ghats. Further, the relationship of key factors such as species richness and abundance of trees with altitude were determined using regression analysis, to understand the influence of altitudinal gradient on the dynamics of seed dispersal mode distribution pattern.

3. Results

3.1. Fruit type

Total species richness and abundance of trees determined for the 60 ha area from the six tropical forest sites of southern Eastern Ghats, India were 272 tree species and 27,412 stems, respectively [24]. List of species that shared greater than or equal to 1% of total abundance is provided in Table 1. From the total tree species inventoried, nine fruit types were recognized, namely achene, berry, capsule, drupe, follicle, nut, pod, samara and syncarp. Among them, drupe formed the predominant fruit type, followed by berry, capsule, pod and follicle, in terms of species richness (Fig. 2) and tree abundance (Fig. 3). One-way ANOVA revealed that there was a significant difference in species richness ($F_{(8,39)} = 32.536, p < 0.0001$) and abundance ($F_{(8,39)} = 7.430, p < 0.0001$) among different fruit types across the six tropical forest sites.

3.2. Dispersal mode

Three major types of seed dispersal modes were recognized from the tropical forests of Eastern Ghats, namely anemochory (seeds dispersed by wind), autochory (seeds dispersed by the exploding fruit) and zoochory (seeds dispersed by animal). The predominant dispersal mode is zoochory with 58% of the total tree abundance and 69% of total species richness, followed by autochory with 30% and 19%, and anemochory 12% and 12%, respectively. The mean (\pm S.D., $n = 120$) species richness per transect for anemochory, autochory and zoochory was 3.72 ± 2.31 , 5.89 ± 2.75 and 19.83 ± 9.57 species (Fig. 4), and the mean (\pm S.D., $n = 120$) tree abundance per transect for anemochory, autochory and zoochory was 28.24 ± 24.89 , 68.03 ± 46.90 and 132.17 ± 83.54 trees (Fig. 5).

One way ANOVA revealed that the three seed dispersal modes varied significantly across the six major tropical forest fragments of southern Eastern Ghats in species richness ($F_{(2,15)} = 39.829, p > 0.0001$) and in abundance ($F_{(2,15)} = 6.867, p > 0.01$). The maximum species richness for anemochory, autochory and zoochory was recorded at KA (25 species), SH (34 species) and KO (121 species), respectively (Fig. 6). And, the minimum value for all the three categories were recorded at BM (6 species, 14 species and 44 species). In case of tree abundance, the maximum value for all the three dispersal modes were recorded at KA (1507 trees, 3181 trees and 4263 trees, respectively) and the minimum values at BM (166 trees, 592 trees and 691 trees) (Fig. 7).

3.3. Relationship analysis

Regression analysis revealed that there is a positive relation ($p < 0.05$) between species richness of trees and altitudinal gradient (elevation of forest location) for the zoochory dispersal mode, and no relation was observed for anemochory ($p > 0.05$) and autochory ($p > 0.05$) dispersal modes (Fig. 8). Similarly, a positive relation was observed between the abundance of trees and altitudinal gradient for zoochory dispersal mode ($p < 0.05$) and no relation ($p > 0.05$) was observed for the others (Fig. 9).

Table 1

List of species that shared greater than or equal to 1% of total abundance (TA), with family, fruit type (FT) and dispersal mode (DM). FT: A- achene; B- berry; C- capsule; D- drupe; F- follicle; N- nut; P- pod; S- samara; Sy- syncarp. DM: A- anemochory; Au- autochory; Z- zoochory.

Species (Family)	TA (%)	FT	DM
<i>Albizia amara</i> (Roxb.) Boivin (Mimosaceae)	7.74	P	Au
<i>Euphorbia antiqorum</i> L. (Euphorbiaceae)	6.65	C	Au
<i>Canthium dicoccum</i> (Gaertn.) Teijsm. & Binn. var. <i>dicoccum</i> (Rubiaceae)	5.05	D	Z
<i>Memecylon edule</i> Roxb. (Melastomataceae)	4.74	B	Z
<i>Chloroxylon swietenia</i> DC. (Flindersiaceae)	3.35	C	A
<i>Nothopegia heyneana</i> (Hook.f.) Gamble (Anacardiaceae)	3.04	D	Z
<i>Gyrocarpus asiaticus</i> Willd. (Hernandiaceae)	2.95	D	A
<i>Pleiospermium alatum</i> (Wall. ex Wight & Arn.) Swingle (Rutaceae)	2.84	B	Z
<i>Anogeissus latifolia</i> (Roxb. ex DC.) Wall. ex Guill. & Perr. (Combretaceae)	2.64	A	Au
<i>Atalantia monophylla</i> (L.) Correa (Rutaceae)	2.61	B	Z
<i>Acacia planifrons</i> Wight & Arn. (Mimosaceae)	2.42	P	Au
<i>Commiphora berryi</i> (Arn.) Engler (Burseraceae)	2.33	D	Z
<i>Drypetes sepiaria</i> (Wight & Arn.) Pax & Hoffm. (Euphorbiaceae)	1.87	D	Z
<i>Wrightia tinctoria</i> (Roxb.) R.Br. (Apocynaceae)	1.75	F	A
<i>Acacia leucophloea</i> (Roxb.) Willd. (Mimosaceae)	1.70	P	Au
<i>Diospyros montana</i> Roxb. (Ebenaceae)	1.55	B	Z
<i>Strychnos potatorum</i> L.f. (Loganiaceae)	1.46	B	Z
<i>Commiphora caudata</i> (Wight & Arn.) Engler (Burseraceae)	1.44	D	Z
<i>Acacia chundra</i> (Roxb. ex Rottl.) Willd. (Mimosaceae)	1.42	P	Au
<i>Acacia horrida</i> (L.f.) Willd. (Mimosaceae)	1.25	P	Au
<i>Premna tomentosa</i> Roxb. (Verbenaceae)	1.25	D	Z
<i>Diospyros ferrea</i> (Willd.) Bakh. var. <i>buxifolia</i> (Rottb.) Bakh. (Ebenaceae)	1.15	B	Z
<i>Ixora pavetta</i> Andr. (Rubiaceae)	1.08	D	Z
<i>Moringa concanensis</i> Nimmo ex Gibs. (Moringaceae)	1.04	C	A
<i>Erythroxylum monogynum</i> Roxb. (Erythroxylaceae)	1.01	D	Z
<i>Givotia rottleriformis</i> Griff. (Euphorbiaceae)	1.00	D	Z

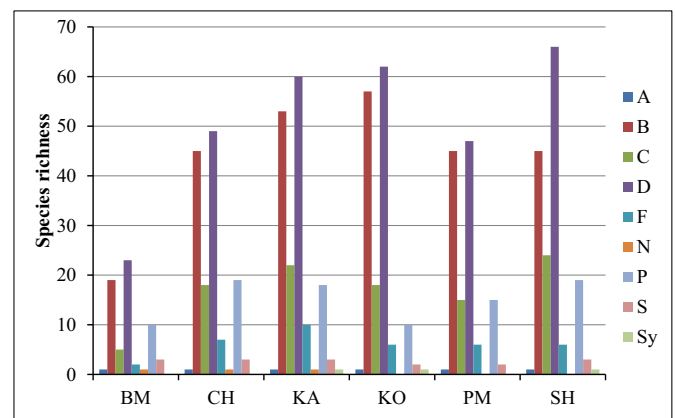


Fig. 2. Species richness of trees under different fruit types for the six forest sites. A- achene; B- berry; C- capsule; D- drupe; F- follicle; N- nut; P- pod; S- samara; Sy- syncarp.

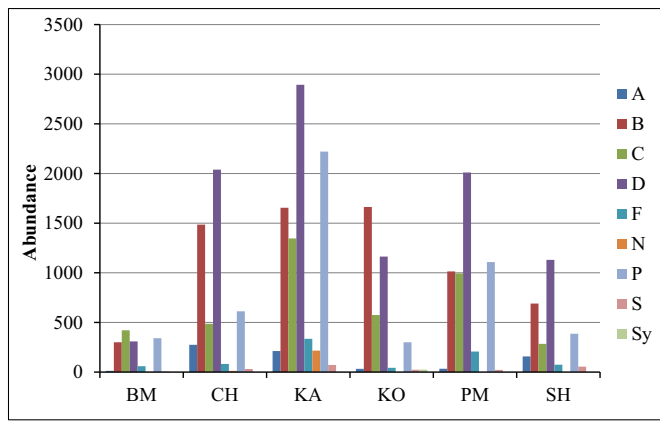


Fig. 3. Abundance of trees under different fruit types for the six forest sites. A- achene; B- berry; C- capsule; D- drupe; F- follicle; N- nut; P- pod; S- samara; Sy- syncarp.

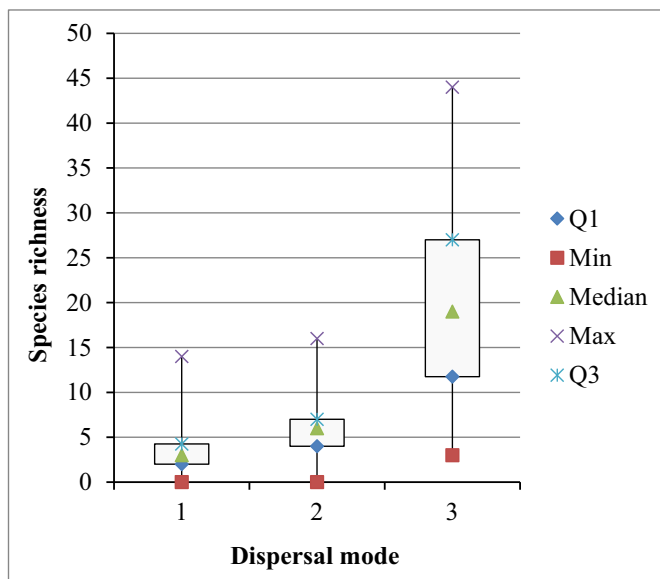


Fig. 4. Box plot showing the distribution of species richness (number of species per transect) among the three dispersal modes ($n = 120$ for each DM): anemochory (1), autochory (2) and zoochory (3).

4. Discussion

Understanding the seed dispersal pattern of any forest system is essential for the success of biodiversity conservation of that system [25]. The present study is the first report on the seed dispersal pattern of tree species from the tropical forests of Eastern Ghats, India. The 272 tree species recorded from these forests were categorized into three major seed dispersal modes based on fruit type of each species. Zoochory was the predominant dispersal mode which shared 69% of total species richness and 58% of total tree abundance. While, the anemochory and autochory dispersal modes shared 31% of the total species richness and 42% of the total tree abundance. Also, one way ANOVA pointed that the three seed dispersal modes varied significantly across the six major tropical forests of southern Eastern Ghats in species richness ($p > 0.0001$) and in abundance ($p > 0.01$). This reveals the dominance of zoochory over the anemochory and autochory dispersal modes in terms of species richness as well as tree abundance in Eastern Ghats of India.

In the present study, species richness of zoochory dispersal mode ranged from 66% in CH to 77% in KO. When compared, the results of the

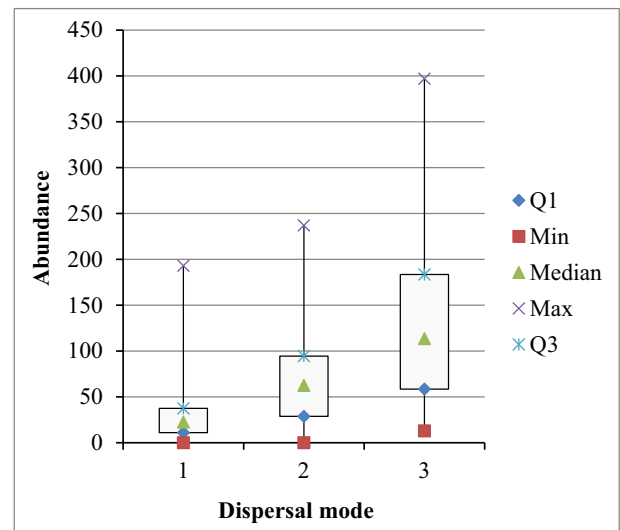


Fig. 5. Box plot showing the distribution of tree abundance (trees per transect) among the three dispersal modes ($n = 120$ for each DM): anemochory (1), autochory (2) and zoochory (3).

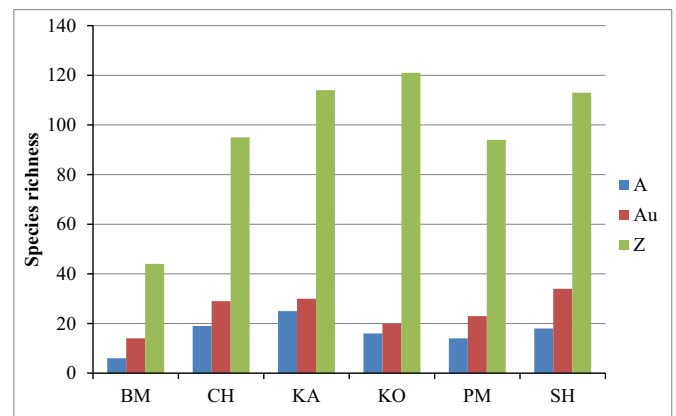


Fig. 6. Species richness of the three dispersal modes for the six major tropical forest sites of southern Eastern Ghats. A - anemochory, Au - autochory, Z - zoochory.

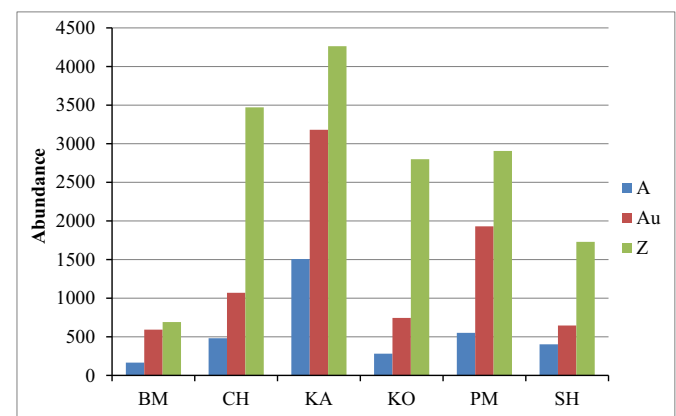


Fig. 7. Abundance of trees under the three dispersal modes for the six major tropical forest fragments of southern Eastern Ghats. A - anemochory, Au - autochory, Z - zoochory.

present study falls in line with similar estimates showcasing the

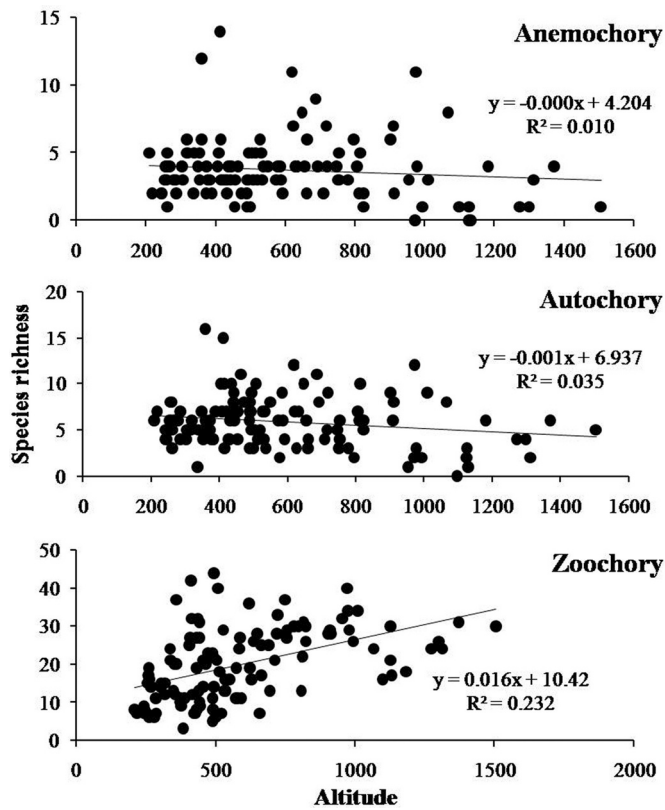


Fig. 8. Results of regression analysis between species richness and altitudinal gradient for the three dispersal modes.

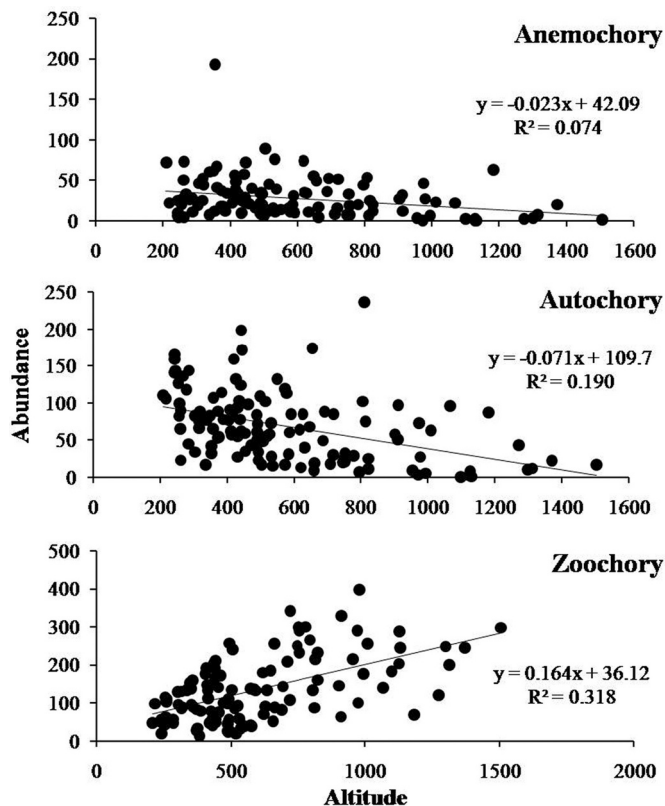


Fig. 9. Results of regression analysis between the tree abundance and altitudinal gradient (elevation of forest location) for the three dispersal modes.

prevalence of zoochory domination in seed dispersal reported from other tropical forest regions ranging from 50% to 94% [26,27]. Ganesh & Davidar [23] have reported that almost 74% of the species out of the total 82 tree species were dispersed by zoochory mode (birds and mammals) from a wet evergreen forest of Western Ghats biodiversity hot spot in India. While, Datta & Rawat [15] have reported that 78% of tree species (out of 128 species) depend on zoochory dispersal mode at a tropical semi-evergreen forest in northeastern India. Also, high percentage of zoochory has been reported for tropical forests elsewhere [28]. In tropical forests with high rainfall, many plants produce fleshy fruits adapted to animal consumption, however in dry environments anemochory and other abiotic dispersal modes occur substantially [29]. This can be explained here in this study rainfall is comparatively high and that support production of fleshy fruits in uphill forests.

The difference in richness and abundance among the sites may be attributed to difference in site area, anthropogenic activities, elevational gradients, forest types and variation in animal diversity, and further research is needed to discuss on these topics.

Desiccation is a major barrier to the survival of fleshy-fruit seeds, which have high water content, soft seed coats, and low germination percentages in abandoned pastures. Seeds with low water content are less susceptible to desiccation in open areas, which is a major barrier for the survival of fleshy-fruit seeds, which have high water content, soft seed coats, and low germination percentages [30]. Forest fragmentation has been a major danger to forest health around the world; reduced seed distribution and seedling recruitment are two of the most common outcomes [31]. Fragmentation affects dispersal of zoochorous species indirectly. It affects the dispersal of animals and often results in the absence of suitable species to disperse fleshy fruits. In contrast to animal-dispersed seeds, wind-dispersed seeds are mostly unaffected by fragmentation [30]. Because of the complexity of plant-pollinator interactions and the practical difficulties of quantifying these interactions in the forest canopy, the effects of disturbance on the reproductive output of tropical forest trees are mostly unknown [32]. Large-seeded plant species are more vulnerable to forest fragmentation than small-seeded plant species, since large-seeded species rely on a small number of extinction-prone dispersers [33].

Interestingly, a positive relation was observed between the species richness (Fig. 8) and tree abundance (Fig. 9) of zoochory dispersal mode with the altitudinal gradient. And, no relation was observed for the autochory and anemochory dispersal modes. This suggests that the distribution ratio for zoochory dispersal mode both in terms of species richness and tree abundance increase with the elevation of the tropical forests. This can be attributed due to the reason that at high elevations the rainfall is comparatively high supporting the distribution of tropical evergreen and semi-evergreen forests rich in animal dispersed tree species. While at the low elevations the rainfall is low supporting mostly mixed deciduous, dry deciduous, and thorn forests where animal dispersed tree species are also low. Further, zoochorous species have an advantage along elevational gradients as animals can carry their seed up the gradient, whereas the other two methods are less likely to be able to travel appreciably up hill. Both anemochorus and autochorus species tend to disperse downhill rather than uphill, as gravity is working against them. However, further studies on these aspects are warranted to draw a significant statement for the tropical forests of Eastern Ghats. Earlier studies suggest that the higher incidence of zoochory in more humid sites with more rain relative to drier sites, for example, Blundo et al. [34] reported that in subtropical Andean forests zoochory is predominant among tree species in plots with greater rainfall.

The tropical forests of Eastern Ghats are prone to anthropogenic pressures such as forest land encroachment; hill cultivation and quarrying that affect the vegetation. Scientists are concerned about anthropogenic habitat deterioration, fragmentation [35], Climate change [36] and cryptic function loss [37]. The efficacy of seed dispersal mutualisms is expected to decline as a result of anthropogenic habitat change, with implications for plant recruitment and population restoration (i.e. seed

dispersal service) by adjusting both the quantitative (seed removal) and qualitative (seed arrival to safe sites) components of seed dispersal [38]. Not only do plants that provide fleshy fruits support animal populations, but animal populations are required for the trees to disperse or persist. This is a mutualism and the conservation implications are many: loss of the animals may doom the forest and loss of the forest may doom the animals. Hence, there is an urgent need to protect the tropical forests of Eastern Ghats in India, for conservation of tree species particularly the Zoochorous species which support the survival of animals that depend on them.

5. Conclusion

The present study reports that there are three major seed dispersal modes, anemochory, autochory and zoochory recognized for the tree species in the six tropical forests of Eastern Ghats in India. Zoochory was the predominant dispersal mode that shared maximum species richness and tree abundance, which is similar to the earlier studies reported for tropical forests worldwide. Interestingly, in this study, a positive relation was observed between the species richness and tree abundance of zoochory dispersal mode with the altitudinal gradient, but not for other dispersal modes. This reveals that the zoochory increases in species richness and tree abundance with increasing altitude. The present study gives useful information on the distribution of seed dispersal strategies among tree species in the Eastern Ghats' tropical forests, which can be used for conservation planning and management. This study is a prime attempt to understand the dispersal modes of tree species using inventory data, which would encourage young researchers to carry out this kind of work. Seed dispersal experiments [39] are necessary to better understand seed dispersal techniques and regional trends, as well as interactions, trade-offs, and synergistic effects that are significant to seed dispersal and other ecological processes.

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Declaration of Competing Interest

None.

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