Chapter 2. Seed bank composition and frugivore assemblage in abandoned tea plantations

Introduction

Tropical plantations cover large areas and are often located in biodiversity-rich regions of the globe. These plantations are getting abandoned for various reasons (Chapter 1). Once abandoned, they are prone to land degradation leading to soil erosion, invasive species colonisation and other factors (Barbosa et al. 2009; Myers et al. 2000; Chapman and Chapman 1999). Recovery of vegetation in such lands is usually done by afforestation using mostly fast-growing non-native species (Feyera et al. 2002; Otsamo 2000; Parrotta 1995) and such efforts are expected to ameliorate succession of native species (Raman et al. 2009; Harvey 2000; Guariguata et al. 1995). However, colonisation can be complex depending on the type of plantation, the location and overall richness of the region along with the facilitative role of plantation trees in attracting forest seeds through frugivore activity (Chetana and Ganesh 2012; Hartley 2002; Zimmerman et al. 2000; Hunter 1990; Norton 1998; Lugo 1997; Parrotta et al. 1997).

Most studies on colonisation are restricted to tree plantations and only a few to shrub monocultures such as coffee (Komar 2006; Williams-Guillén et al. 2006; Arellano et al. 2005; Pineda et al. 2005; Armbrecht et al. 2004; Ricketts et al. 2001). Unlike coffee and cardamom, tea (Camellia sinensis) is a tree species maintained as shrub with a dense continuous short canopy that precludes any large-frugivore activity. The importance of dispersal and the kind of seeds that get dispersed in tea plantations due to various factors mentioned above are unknown. Such information can help to understand what species can colonise abandoned plantations and what factors (e.g., forest proximity, frugivore activity and others) can influence seed input from the management perspective.
In this chapter, I have estimate the seed bank in both litter and soil, and identify factors that may constrain or facilitate seed dispersal within two abandoned tea plantations. The broad questions are as follows.

1. How does species richness, density and composition of seeds in the seed bank of abandoned tea plantations compare with those in the surrounding forests?
2. How does the proximity of forest influence species richness, diversity, composition, and functional traits of the species in the seed bank of abandoned plantations?
3. How does the frugivore richness, abundance and composition in plantations compare with that in forests?

**Methods**

**Study Area**

The study was conducted in Chinnamanjolai and Netterikal (henceforth CHM and NTK respectively) (Figure 2.1), two, 17-year-old abandoned tea plantations at Vanamamalai inside the Kalakad–Mundanthurai Tiger Reserve (KMTR). The land with a total area of about 193.5 ha is owned by Vanamamalai Jeer Mutt temple trust (Ali and Pai 2001). The mutt is in possession of the land title deed (patta) and has the authority to lease-out the property on a 5-year contract to generate revenue for the temple. The Mutt leased the land to Natesan Company for raising plantations of cardamom, coffee, tea and piper. Tea was grown in about 20 ha (per.comu. Shanker Iyer). After the notification of the KMTR as a Protected Area, there have been issues regarding access to the plantations and litigation exists between the forest department and the lease holder, Natesan Transport Company.

**Chinnamanjolai tea plantation**

The Chinnamanjolai plantation (08° 28’ 20.30” and 77° 29’ 15.70”), is spread over 4.6 ha at an elevation of 950–1100 m asl. It receives an annual rainfall between 700 to 3500 mm as per information provided by the lease holder Natesan Transport Company. More
intensive precipitation occurs from the northeast monsoon (October–December) than the south-west monsoon (June–August). The maximum temperature ranges from 22°C to 33°C and minimum temperatures from 12°C to 26°C. Soil in the region is red, loamy and mixed with un-weathered rocks and due to steep slopes, top soil gets eroded from exposed areas by heavy rains. The plantation was overgrown with invasive species, *Lantana camara* (*henceforth* lantana) and is surrounded by deciduous and evergreen forests (see Appendix 3.1).

**Netterikal tea plantation**

Netterikal plantation (08° 29′ 06.64″ and 77° 28′ 43.76″), is spread over 5.3 ha and lies on a plateau between 1300 to 1350 m asl. It receives rain from both south-west (June–August) and northeast (October–December) monsoons. The mean monthly maximum temperature ranges from 15°C to 28°C and minimum temperature from 11°C to 19°C. Annual rainfall ranges from 900 mm to 5000 mm as per information provided by the lease holder, Natesan Transport Company. Red loamy soil is present and topsoil is rich in organic matter due to the leaf litter present in the abandoned areas. There is luxuriant growth of tea within the plantation with few lantana, *Psidium guajava* and *Citrus sinensis*. The plantation is surrounded by wet-evergreen forest (see Appendix 3.1).

Sampling was done thrice a year based on the seasons. The 1st season was winter (W), January–February following the northeast monsoon; 2nd was first summer (S1) April-May before the south-west monsoon and 3rd was second summer (S2), September–October after the south-west monsoon. Data was collected in 2008 and 2009.
Research design

Species richness and seed density in the plantations were assessed using seed banks. Five permanently marked, 10 × 10-m plots were laid along a linear transect from forests to tea plantations (Figure 2.2 a, b, c). Two of these plots were located in the forest at 100 m (Forest Interior: FI) and 50 m (FE: Forest–tea-Edge) from the forest edge. The other three: T25, T60 and T95 were located in the tea plantations at 25 m, 60 m and 95 m, respectively from the centre of the plot to the forest edge (Figure 2.2b). A total of five transects were laid in each plantation separated by a minimum distance of 500 m (Chetana and Ganesh 2012).
Figure 2.2. Schematic diagram of sampling design showing plantations (dotted) and surrounding forests (hatched) (a); plots (10 × 10-m) along linear transect at fixed distance intervals (b); and 1 × 1-m subplot at each corner of the plot (c).
Seed Bank
The seed bank was assessed by two methods: (a). Litter seed bank (LSB) and (b). Soil seed bank (SSB).

(a). Litter seed bank (LSB)
The advantage of this method is its ability to account for all the visible seeds in the surface litter. Data collection was instant, with one-time observation. The limitation of this method is that small and microscopic seeds may be underestimated.

Surface litter and soil were collected within 1 × 1-m subplots laid at the four corners of a 10 × 10-m plot (Figure 2.2 b, c). Large litter including leaves and twigs were removed manually and soil was passed through sieves of different pore sizes (0.5 cm\(^2\) and 1.0 cm\(^2\)). Seeds were collected and identified by comparing with reference collection and regional flora (Gamble and Fischer 1915–1935). Unidentified seeds were preserved for identification later.

(b). Soil seed bank (SSB)
The advantage of this method is that many microscopic seeds can be recorded by using nursery germination technique. The limitation is that many non-viable seeds may not be recorded by this technique. Further, it is time-consuming to keep monitoring from nursery germination. However, by using both these methods a complete profile of the seed bank can be obtained.

Subsurface soil was collected using the soil-corer method. The corer was a cylindrical zinc alloy; the sampling cylinder had a diameter of 4.7 cm and length of 10 cm. The soil core was collected by pressing over the soil and rotating the cylinder with the attached rod. At some places, because of the hardness of the soil, more pressure had to be applied. The soil, including all non-woody litter, was sampled, yielding about 173.56 cm\(^3\) (volume of soil) of soil per sample. In each 10 ×10-m plot, four corners were sampled and soil was pooled at the plot level (\(V = 694.24\) cm\(^3\)). The core samples were stored separately in a clean plastic bag, labelled with a unique code and transported to a temporary shade house.
and later shifted to a nursery. The collected samples were placed on benches in a shade house receiving 30–40% of full sunlight. Soil samples were placed in plastic cups (with a diameter of 13 cm and depth of about 5 cm and bottom diameter of 6 cm). The bottom of the flats was lined with a single layer of newspaper to prevent seed loss though the drainage holes, while still allowing for adequate drainage. Eight cups of sterilised sand used as control were prepared in a pressure cooker and each cup had 1 cm of sand to check for seed contamination of forest soil samples in the nursery.

Moist soils when stored for long can be subjected to fungal infestation leading to decrease in seedling emergence. The collected corer soils could only be transferred from the site to the nursery in a day or two after collection because of the remote location of the field site. To avoid any bias in seedling emergence due to this delay, I conducted a preliminary experiment to test the difference in germination of seeds in corer samples stored for one day and those stored for five days in the same habitat. There was no significant change in species compositions between the days ($t$-test; $t_{(2-tail)} = -1.186$, $n = 10$, $p = 0.25$). The seedling emergence in the nursery was monitored initially every fortnight and later standardised to 4 weeks.

Majority of the seedlings emerged within 8 to 12 weeks and very few species emerged after 24 weeks. Seedlings were however monitored for 48 weeks (1 year) since many species could be identified only after the seedlings develop normal leaves that resembles their parent as few species had polymorphic leaves (e.g., *Toddalia asiatica*, *Acronychia pedunculata*) which were relatively different from the adult plant leaves. We did not examine the soil for remaining seeds at the end of the experiments due to difficulty in identifying the microscopic seeds and no reference collections of such species being available for identification. All attempts were made to identify seedlings to species level, and in few cases germinated seedlings were assigned to family and genus levels, based on character of leaf and branching patterns using Gamble and Fischer (1915–1936). Seedlings that were identified were uprooted from the cups. A collection of dried specimens of seedlings is preserved at the ATREE herbarium. Despite the best efforts, considerable number of seeds remained unidentified. These seeds were categorised in to
distinct morphological groups and referred by numbers in data analysis. Obvious sprouts from rhizomes and other non-seed germinates (e.g., ferns) were not included in our analysis. Seedlings were protected from insect herbivory using organic pesticides to avoid killing earth worms in the soil.

Only a few species of plants germinated in the control cups. Seeds of these species were also observed growing on the floors and in the crevices of the shade house. Since these species were also found in low densities in the sample cups, they were considered to be shade house contaminants. The contaminants were not counted in any calculations.

Functional traits of seeds found in the seed bank, were categorised as below –

1. **Dispersal modes**

Seeds of each species collected from the litter and soil were classified into different dispersal modes based on our field observations, morphological features and published works on seed dispersal modes available from the same forest (Ganesh and Davidar 2001). Seeds were classified into six dispersal modes; bird (B), bat (Bt), mammal (excluding bats) (M), bird–mammal (dispersed by both birds and mammals) (BM), bat–other mammals (dispersed by bats and other mammals such as civets) (BtM), and passive (dehiscent, wind-dispersed, water and others) (Pa) (Chetana and Ganesh 2012).

2. **Life-forms**

Life-forms were classified into herbs, shrubs, climbers and trees (Gamble and Fischer 1915–1935). Further, under each life-form category, seed count was summed up and the mean was calculated.

3. **Seed size**

The seeds were grouped based on their diameter and classified as microscopic (Micro) = \( \leq 0.1 \) cm; small (S) = 0.1–0.5 cm; medium (M) = >0.5–1.5 cm and large (L) = >1.5 cm.
**Frugivores and Seed dispersers**

Frugivores were classified into two categories: volant and non-volant. The volant taxa included birds and bats, whereas non-volant taxa comprised small frugivorous mammals.

**Volant Taxa – Birds**

Frugivore birds were enumerated by using the point count method in each season for two consecutive years within each plantation. Data was collected seasonally from 2008 to 2009 (February, May, and September–October). The sampling was done at each site for 3 to 4 consecutive days, depending on the weather conditions. The observations were done from 06.00 am to 09.00 am (Sutherland 1996; Hutto et al. 1986). At each point, 15 minutes (min) were allotted, of which the first 5 min was spent in allowing the birds to get used to the observer’s presence. No data was collected during this period. Data collection happened only in the next 10 min. At each point, bird presence was recorded and the number of birds counted within 20 m from the point. Beyond 20 m, only presence of the species was considered. A minimum distance of 500 m was kept between sample points and the distance was walked in 10 min. The point count data was collected in both plantations and forests. The forest point count was carried about at 100 m from the forest–tea edge while plantations points were spread all over the area. At each point count, weather conditions were also recorded. Sampling was avoided during thick mist, high wind, or rain. No attempt to stratify sampling at different distances from the forest edge was made because of the small size of the plantations.

**Bats (indirect method)**

I did not attempt to capture bats and identify the species. Seeds dropped by bats in clusters (at feeding roosts which are temporary) under the trees in the plantations and adjacent forest were used to infer presence of bat frugivory at the site.

**Non-volant taxa (indirect method): Camera trap method**

Infrared film camera traps built by Centre for Electronics Design and Technology (CEDT), Indian Institute of Science, Bangalore were used to record non-volant mammalian frugivores frequenting the plantations (Prasad et al. 2010; Chetana and
Two cameras were installed near trails in the tea plantations and in the surrounding forests simultaneously. The cameras were fixed at 0.5 m above the ground and 1.5 to 2 m from the trail. The cameras were set on 24-hour mode with 30-second intervals between pictures to minimise the chances of missing any individuals. The camera trap sampling was done during the seasonal sampling time. Each camera was checked every day for battery power and the number of pictures taken. The distance between the cameras was maintained at a minimum of 1 km and kept on different trails. The cameras were kept for a minimum of 3 consecutive days at each site.

**Data analysis**

Species richness refers to total species recorded in 1 × 1-m sub-plot and similarly seed density refers to total seeds recorded in each subplot (Magurran 2004). Cumulative species richness, mean species richness per subplot and mean seed density per subplot was used to compare between plantations and forests unless mentioned otherwise during the analysis. Similarities in the community composition across plantations (i.e., CHM and NTK) were examined using the grouped average link Bray–Curtis similarity index (van Tongeren 1987). A similarity of 0% means that nothing is common between the two sites and 100% means that the sites share all the species.

The community composition was analysed with a one-factor permutational multivariate analysis of variance (PERMANOVA) between the plantations. One of the sites was an independent factor and was used to test the differences among species. This test is ideal in situations where the datasets represented multiple response (i.e., species) and multiple objects (i.e., transect observations) (Anderson 2001a, b). Moreover, PERMANOVA can handle large multiple species datasets containing more species than replicates with the matrix having numerous zeros (McArdle and Anderson 2001). For this analysis, the species composition matrix was standardised by row totals, and Bray–Curtis distance measure was used as the basis with 9999 permutations. Pairwise comparisons based on Monte-Carlo (MC) randomization with 4999 permutations were performed to test for differences among the plantation types.
I estimated the mean species richness (± SD, standard deviation) through individual-based Coleman’s rarefaction method by Gotelli and Colwell (2001). Further, cumulative species richness was tested by using the ‘rich’ package by Rossi (2011). To estimate species richness of seeds among distance classes within each plantation, at each distance (i.e., FI, FE, T25, T60, T95) Shannon diversity index ($H'$) and Evenness ($E$) were calculated.

**Dispersal modes**

Species richness and seed densities in each dispersal mode were compared across four distance classes in each plantation, using non-parametric Kruskal–Wallis ANOVA. Since bat (Bt) and mammal (M) modes were not represented in all the distance intervals, they were excluded from the analysis. Species richness and seed density under various dispersal modes are from litter seed bank except for Passive (Pa) mode which was obtained from soil seed bank. This is because passively dispersed species were better estimated by SSB method. The unidentified species were excluded from the analysis. Percentage of dispersal modes in each site was calculated based on the total species available in the plantation-forest matrix. Similar, analysis was performed for life-forms and seed size.

A $G$-test was performed to test for differences in distribution of species richness and seed density in forests and plantations across dispersal modes, life-forms and seed sizes. These followed the statistical rule by Kindt and Coe (2005). Further distances from forest F (i.e., mean of FI and FE) to plantations were tested using nonparametric Kruskal–Wallis ANOVA.

**Frugivores**

The differences in species richness and abundance across sites were tested using the unequal variance $t$-test. The species were further classified as – canopy (C), midstorey (M) and understorey (U). The non-flying frugivore mammal’s presence was based on camera trap capture. The relative abundance of each bird was expressed in per minute.
and relative abundance of each mammal was expressed as captures/hr (Chetana and Ganesh 2007).

All analyses were performed using free statistical software R 2.12.1 (R Development Core Team 2011) using packages of ‘vegan’, ‘BiodiversityR’, ‘Rich’, except community composition analysis which was done using PERMANOVA (Anderson 2001a, b).

Results

Seed bank in tea plantations and forests

Species richness and seed density
Total number of species recorded in the seed banks (both LSB and SSB) of forest–tea matrix was 187 (Appendix 2.1). Forests accounted for 82% (153/187) and plantations 68% (127/187) of the total species. About 19% (35/187) of the species were unique to plantations and 33% (61/187) unique to forests. At the plantation level, in CHM, 121 species were recorded in the tea–forest matrix, of which 78% (94/121) were recorded in forests and 38% (80/121) in plantations. At NTK, 144 species were recorded in the tea–forest matrix, of which 81% (116/144) were recorded in forests and 60% (87/144) in plantations. Between 8-17% of species could not be identified to species level within the forest-tea matrix at both sites (Table 2.1).

The total species recorded in the litter seed bank (LSB) was 131 which accounts for 70% (131/187) of the total species recorded in the tea-forest matrix. Forests accounted for 82% (108/131) and plantations 63% (82/131) of the species while about 18% (23/131) was unique to plantations and 37% (49/131) unique to forests (Table 2.1). At the plantation level, in CHM, 81 species were recorded of these, 78% (63/81) were recorded in forests and 65% (53/81) in plantations. At NTK, 98 species were recorded of these; 86% (83/98) were found in forests and 51% (49/98) in the plantations. Between 8-20% of species could not be identified to species level within the forest-tea matrix in both sites.
Of the 9299 seeds recorded in the litter-seed bank in the forest–tea matrix, forests accounted for 50% (4649/9299) and plantations 50% (4650/9299). At the plantation level, in CHM, 49% (1785/3643) was found in forests and 51% (1858/3643) in plantations. Similarly at NTK, 51% (2864/5656) was found in forests and 49% (2792/5656) in plantations (Table 2.1).

Since LSB and SSB indicate similar patterns and in general SSB captures much lower number of large, medium and small-sized seeds than micro-sized seeds, LSB was used for all analysis. Though SSB captures more number of species with fever seed samples, it does not adequately capture large and medium sized seed species.

Table 2.1. Species richness, density, diversity, and evenness of seeds recorded in LSB and SSB in the abandoned plantations of CHM and NTK at different distances from the forests.

<table>
<thead>
<tr>
<th>Distance</th>
<th>Litter-seed bank (LSB)</th>
<th>Soil-seed bank (SSB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Species richness (total seeds)</td>
<td>Mean ± se (m⁻²)</td>
</tr>
<tr>
<td>CHM</td>
<td>F 63 (1785)</td>
<td>07.43 ± 1.30</td>
</tr>
<tr>
<td></td>
<td>T 53 (1858)</td>
<td>05.27 ± 1.04</td>
</tr>
<tr>
<td></td>
<td>FI 38 (0638)</td>
<td>05.31 ± 1.22</td>
</tr>
<tr>
<td></td>
<td>FE 51 (1147)</td>
<td>09.55 ± 2.25</td>
</tr>
<tr>
<td></td>
<td>T25 48 (1335)</td>
<td>11.12 ± 2.59</td>
</tr>
<tr>
<td></td>
<td>T60 24 (0390)</td>
<td>03.25 ± 1.04</td>
</tr>
<tr>
<td></td>
<td>T95 09 (0133)</td>
<td>01.10 ± 0.14</td>
</tr>
<tr>
<td>NTK</td>
<td>F 83 (2864)</td>
<td>11.93 ± 2.60</td>
</tr>
<tr>
<td></td>
<td>T 49 (2792)</td>
<td>08.11 ± 1.57</td>
</tr>
<tr>
<td></td>
<td>FI 58 (1256)</td>
<td>10.46 ± 1.59</td>
</tr>
<tr>
<td></td>
<td>FE 57 (1608)</td>
<td>13.40 ± 4.99</td>
</tr>
<tr>
<td></td>
<td>T25 36 (1010)</td>
<td>08.41 ± 2.63</td>
</tr>
<tr>
<td></td>
<td>T60 28 (0899)</td>
<td>07.53 ± 2.82</td>
</tr>
<tr>
<td></td>
<td>T95 14 (0883)</td>
<td>07.35 ± 2.51</td>
</tr>
</tbody>
</table>

**Species compositions**

The species compositions of seeds in the seed bank across the two plantations and its surrounding forest showed very distinct natural grouping (Figure 2.3). There was 7% similarity in species composition between plantations and 31% between forests at CHM.
and NTK. Whereas forests and plantations were 34% similar in CHM and only 18% in NTK. Further, non-parametric PERMANOVA indicates that species composition change is highly significant across the two plantations ($F = 6.519$, $df = 1$, $p$ (MC) = 0.0001). Further, Bray–Curtis similarity also confirms distinct clustering of species composition across the two elevations.

Figure 2.3. Dendrogram of the two plantations sampled, using LSB – litter seed bank in Forest (F) and Tea (T). Cluster distances were calculated with the Bray–Curtis similarity index (grouped average link) for the species and density, CHM = Chinnamanjolai, NTK = Netterikal.

Forest proximity

Species richness and seed density

Species richness of seeds declined with distance from the forest at CHM (Kruskal–Wallis; $\chi^2 = 14.245$, $df = 3$, $p = 0.002$) and at NTK (Kruskal–Wallis; $\chi^2 = 13.97$, $df = 3$, $p = 0.002$). Evenness decreased with distance only in CHM and not in NTK (Table 2.1). Density of seeds declined with distance at CHM (Kruskal–Wallis; $\chi^2 = 13.64$, $df = 3$, $p = 0.003$, Figure 2.4) but not so in NTK (Kruskal–Wallis; $\chi^2 = 6.73$, $df = 3$, $p = 0.08$).
Figure 2.4. Mean species richness and seed density (± se) at varying distances from the forest. FI = forest interior, FE = Forest–tea-edge, T25 = 25 m, T60 = 60 m and T95 = 95 m are distances from forest edge.

In general, as one moves away from the forest, lower species richness and seed density is seen in the plantations. This is true for CHM, but not so with density of seeds in NTK.

LSB in both the plantations (i.e., CHM and NTK) reach an asymptote at 95 m. In case of CHM, it happens with 50 seeds and in NTK with about 200 seeds (Figure 2.5), whereas other distances of 60 m, 25 m and also forests did not show any asymptote even with 240 sub-plots spread across 2 years indicating that species turnover is higher in forests and in plantations closer to forests than further away.
Figure 2.5. Estimated species richness by Coleman’s individual-based rarefaction for CHM = Chinnamanjolai and NTK = Netterikal. F = forest (mean of FI and FE), T25 = 25 m, T60 = 60 m and T95 = 95 m are distances from forest edge.

Cumulative species richness showed significant difference with all distance classes in both the plantations. Only the 25 m in CHM was not different from the forests (Table 2.2).

Table 2.2. Comparisons of differences in cumulative species richness between various distance intervals at 95% confidence level using ‘rich’ (R package). The values indicate differences in species. * $p < 0.05$, ** $p < 0.001$, ns – not significant.

<table>
<thead>
<tr>
<th>Distance intervals (m)</th>
<th>CHM</th>
<th>NTK</th>
</tr>
</thead>
<tbody>
<tr>
<td>F–T25</td>
<td>15 ns</td>
<td>47 **</td>
</tr>
<tr>
<td>F–T60</td>
<td>39 **</td>
<td>55 **</td>
</tr>
<tr>
<td>F–T95</td>
<td>54 **</td>
<td>69 **</td>
</tr>
<tr>
<td>T25–T60</td>
<td>24 **</td>
<td>08 ns</td>
</tr>
<tr>
<td>T25–T95</td>
<td>39 **</td>
<td>22 **</td>
</tr>
<tr>
<td>T60–T95</td>
<td>15 **</td>
<td>14 *</td>
</tr>
</tbody>
</table>
The most species-rich dispersal modes in CHM and NTK were passive, bird–mammal, and bird across forests and plantations (Table 2.3). The distribution of species across different modes did not show significant difference between forests and plantations for both CHM ($G = 1.364$, $df = 4$, $p = 0.85$) and NTK ($G = 2.829$, $df = 5$, $p = 0.58$). In CHM plantation, bird-mammal (BM) accounted for 79%, passive (Pa) 74%, birds (B) 56%, and mammals (M) 50% of species. No exclusive bat dispersed species were seen in CHM. In NTK, Pa accounted for 84%, BM 72%, B 50%, and M 35% of species.

However, unlike species the distribution pattern of seed density in different modes were highly significant between forests and plantations for both CHM ($G = 603.56$, $df = 4$, $p < 0.001$), and NTK ($G = 1299.07$, $df = 5$, $p < 0.001$). In terms of seed density at CHM, BM accounted for 55%, Pa 55%, B 50%, BtM 14%, and M 9% of the seeds, while at NTK, BM 71%, Pa 54%, BtM 28%, B 17%, and M 3%.

### Table 2.3. Mean species richness and seed density (± se) across different dispersal modes encountered in the litter ($m^{-2}$) in forests and plantations. (Pa$^#$ = from soil seed bank in cm$^{-3}$).

<table>
<thead>
<tr>
<th>Dispersal modes</th>
<th>CHM</th>
<th>NTK</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forest</td>
<td>Tea</td>
</tr>
<tr>
<td><strong>Species richness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.15 ± 0.03</td>
<td>0.15 ± 0.03</td>
</tr>
<tr>
<td>BM</td>
<td>0.35 ± 0.05</td>
<td>0.39 ± 0.05</td>
</tr>
<tr>
<td>BtM</td>
<td>0.10 ± 0.02</td>
<td>0.03 ± 0.01</td>
</tr>
<tr>
<td>Bt</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>M</td>
<td>0.33 ± 0.05</td>
<td>0.06 ± 0.01</td>
</tr>
<tr>
<td>Pa$^#$ × 10$^{-3}$</td>
<td>2.11 ± 0.28</td>
<td>1.98 ± 0.25</td>
</tr>
<tr>
<td><strong>Seed density</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0.73 ± 0.29</td>
<td>1.55 ± 0.58</td>
</tr>
<tr>
<td>BM</td>
<td>3.18 ± 1.10</td>
<td>2.64 ± 0.73</td>
</tr>
<tr>
<td>BtM</td>
<td>0.65 ± 0.26</td>
<td>0.07 ± 0.03</td>
</tr>
<tr>
<td>Bt</td>
<td>0.00 ± 0.00</td>
<td>0.00 ± 0.00</td>
</tr>
<tr>
<td>M</td>
<td>1.33 ± 0.34</td>
<td>0.09 ± 0.03</td>
</tr>
<tr>
<td>Pa$^#$ × 10$^{-3}$</td>
<td>4.42 ± 0.67</td>
<td>3.59 ± 0.48</td>
</tr>
</tbody>
</table>
**Distance effect**

*Species richness and seed density*

Species richness in the different dispersal modes declined significantly with distance from forests to the interior of the plantations for birds (Kruskal–Wallis; B: $\chi^2 = 15.41$, df = 3, $p = 0.001$) and passive (Pa: $\chi^2 = 18.10$, df = 3, $p = 0.0004$) but not for bird–mammal (BM: $\chi^2 = 1.11$, df = 3, $p = 0.77$) at CHM (Figure 2.6). At NTK similar decline was evident for birds (B: $\chi^2 = 22.44$, df = 3, $p = 0.0001$); bat–mammal (BtM: $\chi^2 = 15.89$, df = 3, $p = 0.001$), but not for bird-mammal (BM: $\chi^2 = 1.25$, df = 3, $p = 0.73$), and passive (Pa: $\chi^2 = 2.27$, df = 3, $p = 0.51$).

The most common dispersal mode in which seed density declined away from the forests in CHM was bird ($\chi^2 = 15.59$, df = 3, $p = 0.001$) while passive ($\chi^2 = 4.59$, df = 3, $p = 0.20$) and bird–mammal ($\chi^2 = 0.76$, df = 3, $p = 0.85$) also declined. In NTK, bird ($\chi^2 = 23.20$, df = 3, $p = 0.0001$) and bat–mammal ($\chi^2 = 15.84$, df = 3, $p = 0.001$) declined with distance but not bird–mammal ($\chi^2 = 1.03$, df = 3, $p = 0.79$) and passive (Pa: $\chi^2 = 2.02$, df = 3, $p = 0.56$; Figure 2.6).
Figure 2.6. Mean species richness (a) and seed density (x̄ ± se) (b); in different dispersal modes at various distances, from forests to plantations at CHM and NTK. Dispersal modes data is from LSB and only Pa from SSB. FI: forest interior, FE: Forest–tea-edge; T25 = 25 m, T60 = 60 m and T95 = 95 m are distances from forest edge.

In general, density of seeds under different dispersal modes showed variable response to distance from the forests to the plantations. Bird seeds declined with distance while BM did not decline with distance in both CHM and NTK. Pa seeds are generally distributed uniformly across both the plantations (Figure 2.6).
Life-forms

All four life-forms; trees, shrubs, lianas and herbs were recorded in forests and plantations in both CHM and NTK (Table 2.4). In CHM plantation, shrubs accounted for 89% of the species, herbs 80%, tree 62% and liana 44% while in NTK herbs were dominant 83%, liana 65%, trees 54% and shrubs 42%. The distribution of species richness across life-forms did not show significant difference between forests and plantations at CHM ($G$-test: $G = 2.417$, $df = 3$, $p = 0.49$) and at NTK ($G = 4.701$, $df = 3$, $p = 0.19$). In terms of density, at CHM plantation, shrubs were dominant 95% followed by herbs 49%, trees 41% and lianas 7%. Similarly in NTK plantation, shrubs were dominant 97%, followed by herbs 62%, liana 44% and trees 21%. The distribution of seed-density across different life-forms was however different at CHM ($G = 919.26$, $df = 3$, $p = 0.001$) and NTK ($G = 3584.28$, $df = 3$, $p = 0.001$).

Table 2.4. Mean species richness and seed density ($\bar{x} \pm se$) across different life-forms encountered in the litter (m$^{-2}$) of forests and plantations. (herbs*: from soil seed bank in cm$^{-3}$).

<table>
<thead>
<tr>
<th>Life-forms</th>
<th>CHM</th>
<th>NTK</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Species richness</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>herbs $\times 10^{-3}$</td>
<td>2.40 ± 0.31</td>
<td>1.86 ± 0.22</td>
</tr>
<tr>
<td>shrubs</td>
<td>0.06 ± 0.02</td>
<td>0.26 ± 0.03</td>
</tr>
<tr>
<td>trees</td>
<td>0.87 ± 0.12</td>
<td>0.40 ± 0.06</td>
</tr>
<tr>
<td>lianas</td>
<td>0.16 ± 0.03</td>
<td>0.03 ± 0.01</td>
</tr>
</tbody>
</table>

| **Seed density** | | |
| herbs $\times 10^{-3}$ | 5.43 ± 0.86 | 3.52 ± 0.46 | 6.29 ± 1.83 | 6.88 ± 1.10 |
| shrubs | 0.15 ± 0.06 | 1.88 ± 0.47 | 0.24 ± 0.10 | 5.56 ± 1.50 |
| trees | 6.01 ± 1.44 | 2.79 ± 0.91 | 11.09 ± 2.87 | 1.93 ± 0.46 |
| lianas | 0.70 ± 0.20 | 0.03 ± 0.01 | 0.32 ± 0.61 | 0.22 ± 0.12 |
**Distance effect**

Species richness under the different life-form category showed significant increase with distance from forest to the interior of the plantation at CHM for shrubs ($\chi^2 = 14.57, df = 3, P = 0.002$) and a decline for herbs ($\chi^2 = 15.70, df = 3, p = 0.001$) whereas trees and lianas declined marginally (Kruskal–Wallis; $\chi^2 = 6.07, df = 3, p = 0.10$; Figure 2.7). At NTK, trees ($\chi^2 = 10.21, df = 3, p = 0.01$) and lianas ($\chi^2 = 18.38, df = 3, p = 0.0001$) showed significant decline but not shrubs ($\chi^2 = 3.14, df = 3, p = 0.36$) and herbs ($\chi^2 = 2.49, df = 3, P = 0.47$).

In terms of seed density all life forms generally decreased with distance from forests at CHM; shrubs declined significantly ($\chi^2 = 14.57, df = 3, p = 0.002$) while it was not significant for trees ($\chi^2 = 6.31, df = 3, p = 0.09$) and herbs ($\chi^2 = 5.40, df = 3, p = 0.14$). However, at NTK, trees ($\chi^2 = 9.88, df = 3, p = 0.01$) and lianas ($\chi^2 = 18.29, df = 3, p = 0.0001$) declined with distance from forests whereas shrubs increased ($\chi^2 = 3.32, df = 3, P = 0.34$), and herbs showed no clear patterns with distance ($\chi^2 = 2.80, df = 3, p = 0.42$).

In general except for shrubs and herbs, trees and lianas declined with distance from the forests. Shrubs appears to increase in plantations which may be due to the presence of invasive species similarly in herbs which may be due to light loving perennials.
Figure. 2.7. Mean species richness (a) and seed density (b); in different life-forms at various distances (x̄ ± se), from forests to plantations at CHM and NTK. Life-form data is from LSB and herb # from SSB. FI: forest interior, FE: Forest-tea-edge; T25 = 25 m, T60 = 60 m and T95 = 95 m are distances from forest edge.

**Seed size**

The distribution of species in each seed size category did not show significant difference between forests and plantations for both CHM ($G$-test: $G = 0.676$, $df = 3$, $p = 0.87$), and NTK ($G = 7.270$, $df = 3$, $p = 0.06$). In CHM species with micro sized seeds 76% were most common followed by small 67%, large 63%, and medium 61% sized seeds. In NTK plantations also micro seeds 83% dominated followed by medium 54%, small 49%, and large seeds 33%.
The distribution patterns of seed density in each seed size class was highly significant between forests and plantations at CHM ($G = 325.58$, $df = 3$, $p = 0.001$) and NTK ($G = 657.28$, $df = 3$, $p = 0.001$; Table 2.5).

In terms of seed density at CHM small seeds 59% were most common, followed by medium 53%, micro 46% and large 8% seeds whereas in NTK micro seeds 65% were most common followed by small 46%, large 31% and medium 17%.

Table 2.5. Mean species richness and seed density ($\bar{x} \pm se$) across different seed size encountered in the litter (m$^{-2}$) of forests and plantations. (Micro$^\#$: from soil seed bank in cm$^3$).

<table>
<thead>
<tr>
<th></th>
<th>CHM</th>
<th></th>
<th>NTK</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forest</td>
<td>Tea</td>
<td>Forest</td>
<td>Tea</td>
</tr>
<tr>
<td><strong>Species richness</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro$^#$ x 10$^{-3}$</td>
<td>3.51 ± 0.33</td>
<td>2.30 ± 0.28</td>
<td>3.89 ± 0.55</td>
<td>4.48 ± 0.43</td>
</tr>
<tr>
<td>Small</td>
<td>0.52 ± 0.07</td>
<td>0.35 ± 0.05</td>
<td>0.32 ± 0.05</td>
<td>0.11 ± 0.02</td>
</tr>
<tr>
<td>Medium</td>
<td>0.48 ± 0.07</td>
<td>0.38 ± 0.05</td>
<td>0.90 ± 0.11</td>
<td>0.33 ± 0.04</td>
</tr>
<tr>
<td>Large</td>
<td>0.23 ± 0.03</td>
<td>0.05 ± 0.01</td>
<td>0.43 ± 0.06</td>
<td>0.09 ± 0.02</td>
</tr>
<tr>
<td><strong>Seed density</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Micro$^#$ x 10$^{-3}$</td>
<td>8.07 ± 0.98</td>
<td>4.55 ± 0.60</td>
<td>3.89 ± 0.54</td>
<td>4.48 ± 0.42</td>
</tr>
<tr>
<td>Small</td>
<td>2.57 ± 0.62</td>
<td>2.47 ± 0.69</td>
<td>0.94 ± 0.23</td>
<td>0.53 ± 0.29</td>
</tr>
<tr>
<td>Medium</td>
<td>2.76 ± 0.75</td>
<td>2.07 ± 0.48</td>
<td>8.73 ± 2.65</td>
<td>1.17 ± 0.22</td>
</tr>
<tr>
<td>Large</td>
<td>1.26 ± 0.33</td>
<td>0.08 ± 0.03</td>
<td>2.25 ± 0.55</td>
<td>0.68 ± 0.23</td>
</tr>
</tbody>
</table>

**Distance effect**

Species richness within different seed size classes showed significant decline with distance from forest at CHM for micro seeds (Kruskal–Wallis; $\chi^2 = 21.07$, $df = 3$, $p = 0.0001$); small seeds ($\chi^2 = 8.20$, $df = 3$, $p = 0.04$); medium seeds only marginally declined ($\chi^2 = 0.59$, $df = 3$, $p = 0.89$; Figure 2.8) and no large seeds were recorded beyond 60 m. In NTK, species richness for small ($\chi^2 = 13.76$, $df = 3$, $p = 0.003$); and large seeds ($\chi^2 = 25.93$, $df = 3$, $p = 0.0001$) declined significantly with distance but not for micro seeds ($\chi^2 = 0.98$, $df = 3$, $p = 0.80$) and medium sized seeds ($\chi^2 = 6.55$, $df = 3$, $p = 0.08$) which only showed a gradual decline.
In terms of seed density, at CHM, small ($\chi^2 = 10.44, df = 3, p = 0.01$); and micro seeds ($\chi^2 = 12.1, df = 3, p = 0.007$) declined with distance from forest while medium sized seeds only marginally declined ($\chi^2 = 0.44, df = 3, p = 0.93$; Figure 2.8). In NTK, seed density for small ($\chi^2 = 12.68, df = 3, p = 0.005$), and large seeds ($\chi^2 = 28.40, df = 3, p = 0.0001$) declined but not micro seeds ($\chi^2 = 2.68, df = 3, P = 0.44$) and medium sized seeds ($\chi^2 = 6.73, df = 3, p = 0.08$).

Figure 2.8. Mean species richness (a), and seed density (b) in different seed size classes (length) across various distances from forests to plantations (x ± se) at CHM and NTK. Micro # = ≤ 0.1 cm (from SSB); S = small (>0.1 to 0.5 cm); M = Medium (>0.5 to 1.5 cm) and L = large (>1.5 cm).

In general, large, medium, and small seeds declined with distance both in terms of species and seed density. Whereas micro sized seeds were not affected in NTK both in terms of species richness and density.
Frugivore assemblage

A total of 17 species of volant taxa that includes 14 species of frugivore birds were recorded. The sloth bear (*Melursus ursinus*) and Brown palm civet (*Paradoxurus jerdoni*) are the two non-volant seed dispersers (Appendix 2.2a, b) recorded in the forest–plantation matrix at CHM and NTK.

Volant Taxa

*Frugivore birds – Species and abundance*

In CHM, 12 frugivore bird species were recorded in the forest–tea matrix; of these 9 were recorded in the forest and 8 in plantations and there was no significant difference in species across forests and plantations (*t*-test, unequal samples; *t* = −0.13715, *n*₁ = 25, *n*₂ = 29, *p*(2-tailed) = 0.89). In NTK, 13 species of frugivore birds were recorded all 13 of these in plantation and 12 in forest and no significant change in species richness across forests and plantations (*t* = −0.428, *n*₁ = 53, *n*₂ = 36, *p*(2-tailed) = 0.66).

Frugivore diversity and evenness at CHM was marginally higher in forest than plantations (Table 2.6). In contrast at NTK, diversity and evenness was marginally higher in plantation than in forest.

<table>
<thead>
<tr>
<th></th>
<th>Species richness (Abundance)</th>
<th>Shannon (<em>H'</em>')</th>
<th>Evenness (<em>E</em>)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CHM</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest (<em>n</em>₁ = 25)</td>
<td>9 (50)</td>
<td>1.83</td>
<td>0.691</td>
</tr>
<tr>
<td>Tea (<em>n</em>₂ = 29)</td>
<td>8 (79)</td>
<td>1.47</td>
<td>0.545</td>
</tr>
<tr>
<td><strong>NTK</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest (<em>n</em>₁ = 53)</td>
<td>12 (149)</td>
<td>1.78</td>
<td>0.494</td>
</tr>
<tr>
<td>Tea (<em>n</em>₂ = 36)</td>
<td>13 (113)</td>
<td>1.85</td>
<td>0.488</td>
</tr>
</tbody>
</table>
The total number of birds recorded at the forest–tea matrix in CHM was 129 individuals (from 54 point count), of these, plantation accounted for 61% and forest 39%. There is no significant change in abundance between forest and plantation ($t = -1.0424$, $n_1 = 25$, $n_2 = 29$, $p_{(2\text{-tailed})} = 0.30$). At NTK, of 262 individuals recorded (from 89 point count), 43% were found in the plantation and 57% in the forest and there was no significant change in abundance between forests and plantation ($t = -0.487$, $n_1 = 53$, $n_2 = 36$, $p_{(2\text{-tailed})} = 0.62$) (Table 2.6).

The frugivore guild at CHM was further classified into canopy (8 species), midstorey (1) and understorey (3) dwellers. Higher number of canopy species was seen in forests than in plantations, whereas higher numbers of understorey species were recorded in the plantations and no differences noticed for midstorey species. In NTK also showed higher number of canopy species (7), followed by understorey (4) and midstorey species (2) was recorded. Overall, both forests and plantations had higher number of species in the canopy and understorey, followed by midstorey (Figure 2.9).

![Figure 2.9. Cumulative species richness and mean abundance across (± se) CHM, NTK and surrounding forests: C = Canopy; M = Midstorey and U = Understorey.](image-url)
The dominant frugivore birds in the CHM forest–plantation matrix were *Pycnonotus jocosus* (Red-whiskered bulbul), *Acritillas indica* (Yellow-browed bulbul) and *Hypsipetes leucocephalus* (Black bulbul). In NTK, the forest was dominated by *Hypsipetes leucocephalus* followed by *Acritillas indica* and *Pycnonotus jocosus*; whereas in plantations, *Pycnonotus jocosus* was dominant followed by *Hypsipetes leucocephalus* and *Acritillas indica* (Figure 2.10, Appendix 2.2a). Interestingly, *Megalaima viridis* (White cheeked barbet) a major frugivore was not recorded in the CHM tea plantations and *Pycnonotus jocosus* was in low abundance in NTK forest, but high in NTK tea plantations.

![Figure 2.10. Relative abundance of avian frugivores in the forests and tea plantations at CHM and NTK. Red whiskered bulbul (RBUL); Black bulbul (BBUL); Yellow browed bulbul (YBUL); Indian Scimitar babbler (ISCH); Mountain imperial pigeon (MIMP); Oriental white eye (OWTE); Kerala Laughing thrush (KLTH); Eurasian blackbird (EBLA); White-cheeked barbet (WBAR); Nilgiri flycatcher (NFLY); Rosefinch (RFIN); Wynaad laughing thrush (WLTH); Red-vented bulbul (RVBU) and Fairy-bluebird (FBLU).](image-url)
In CHM, frugivore composition was 56% similar between forest and plantations, and in NTK, it was 63%. The two plantations shared about 58% and forests about 40% of species (Figure 2.11).

![Dendrogram of frugivore composition](image)

**Figure 2.11.** Dendrogram of the frugivore composition in the two plantations. Cluster distances were calculated with the Bray–Curtis similarity index (grouped average link) for the species and seed density. CHM = Chinnamanjolai, NTK = Netterikal, F = Forest and T = Tea.

**Frugivore bats**

Bat seed droppings indicated the presence of frugivore bat species within the plantations and the surrounding forest. Earlier studies from the same landscape recorded three frugivore species of *Cynopterus sphinx*, *Cynopterus brachyotis* and *Latidens salimalii*, which are the potential seed dispersers in this plantation (Appendix 2.2b).

**Non-flying mammals (non-volant)**

Two frugivorous species were recorded in both the plantations of CHM and NTK in the camera traps. The capture rate for *Paradoxurus jerdoni* (Brown palm civet) was more in NTK than CHM, whereas that of *Melursus ursinus* (Sloth bear) was higher in CHM than NTK (Figure 2.12; Appendix 2.2b).
Discussion

Forest, Frugivores and plantations

The proportion of native species in the surface litter of the plantations was about 68% of that recorded in adjacent forests, while the seed density was about 50%. In the adjacent managed tea plantation at about the same elevation (1250 m), species richness in litter was in the range of 1/6–1/14 times and seed density was 1/500 times of that found in the forests (Chetana and Ganesh 2012). Though species input appears to be similar in both managed and abandoned plantations, density of seeds, assuming was similar to managed plantations before plantations were abandoned, has increased by about 125 times (from 1/500 to 1/4) in the last 17 years in abandoned plantations, which is substantial, but still not similar to the adjacent forest. Several factors could influence seed arrival in the plantations (Chetana and Ganesh 2012). These could include, among others, availability of seeds in the neighbourhood, distance of such seed sources (Martínez-Garza et al. 2009), phenology of trees in the surrounding forests (Guevara et al. 2004), frugivore activity and availability of suitable habitats such as perches or remnant trees (Zanini and Ganade 2005; Holl 2002; Holl et al. 2000; Galindo-González et al. 2000; Holl et al. 2000; Duncan and Chapman 1999; Holl 1998), as discussed in the next few sections.
Ninety-two % of the seeds in terms of seed density that arrived in the plantations were animal-dispersed (i.e., volant/non-volant) and the rest were passively dispersed. Therefore, frugivores play a major role in carrying seeds into the plantations. The dominant frugivores were bulbuls among birds and *Paradoxurus jerdoni* (brown palm civet) and *Melursus ursinus* (sloth bears) among mammals (Appendix 2.2a). Though there was no significant difference in abundance of birds between plantations and forests, higher abundance was noticed at the higher elevation (NTK) than in the lower elevation (CHM). This may be due to the availability of more fruit resources in NTK such as *Maesa indica* which usually fruits all through the year, whereas in CHM fruit source was low other than overgrown lantana. In terms of seed dispersal service, the assemblage of avian frugivores available within the forest–plantation matrix may not be enough to disperse all the native species found in the region. The dominant dispersers (bulbuls) in the plantation may be able to disperse species with small and medium-sized seeds available in the surrounding forests. Large frugivore birds such as hornbills and pigeons though present, are in low abundance and may not perch frequently within the plantation as only a few tall trees are available. In addition, plantation size could also matter as many birds, especially large frugivores may avoid small open habitats (*pers. obs.*), especially when forests are seen close by and thereby not contribute to dispersal.

Earlier studies from tropical rainforest regions have shown that agroforestry plantations, logged forests and secondary successional forests generally harbour fewer bird species and have altered community composition as compared to primary forests (Raman *et al.* 1998; Thiollay 1995; Johns 1992; Daniels *et al.* 1990). Unlike other tree or shrub plantations, tea habitats have dense undergrowth of tea plants and only few native early-successional species such as *Viburnum punctatum, Litsea wightiana,* and *Maesa indica* are found here. Small frugivores such as bulbuls get attracted by plenty of fruits produced by these species. This could be the reason we did not find significant difference in either the frugivore richness or abundance across the forests and plantations while there was a 56-63% difference in their composition.
Bats are another set of frugivores which can help in dispersing seeds far away from the trees. The plantations may not be so attractive to bats since it has been shown that retaining a heterogeneous tree cover attracts diverse bat assemblages (Medina et al. 2007; Gorchov et al. 1993; Thomas et al. 1988; Charles-Dominique 1986). In abandoned plantations though, the trees have colonised in the last 17 years, are still small and not very diverse or do not have dense canopy cover that can attract frugivorous bats. Moreover not many of the early successional species are bat-dispersed and therefore in terms of fruit resource inside the abandoned plantations, it is still not attractive to bats. Therefore, the ability of bats to help disperse seeds into the tea plantations seems limited even 17 years after abandonment.

Two main factors that may prevent the frugivores from venturing into the plantations are limited food and habitat suitability (Chetana and Ganesh 2012). Tea plantations are ‘green deserts’ for frugivores as they lack fruit resources and tea fruit itself is not eaten by frugivores. The second factor could be the lack of adequate tree cover and most of the plants were not more than 10 m in height, moreover as seen in CHM, lantana has colonised most parts of the tea plantation and in NTK, tea is the dominant vegetation thus making the habitats less attractive for frugivores. The frugivore birds were assessed only along the forest edge (100 m), which could be the reason we did not record all the frugivore birds in the forests of CHN and NTK plantations and only inhabitants of open, understorey and forest edge species were recorded.

**Dispersal limitation**

Seed input is also a function of seed source and distance from the source. Seed species richness and seed density decreased with distance of plantation from the forest. In the case of lower elevation CHM plantation, at 95 m from the forests only 11% of species and 1% of seeds were dispersed into the plantations. In NTK, it was 14% and 31%, respectively. Overall, such sharp decline in forest species within 95 m of the forest edge even after 17 years of abandonment indicates limitations of dispersal (Figure 2.11).
An earlier study in the same landscape, showed that frugivore richness was low in the southern Western Ghats compared to elsewhere in the old world tropics (Ganesh and Davidar 2001; Raman 2001). Many large seeded species were late successional species such as Palaquium ellipticum, Artocarpus heterophyllus Myristica beddomei and Agalia sp., dispersed by mammals, large birds such as hornbills or pigeons (Chetana, H.C. unpubl, Ganesh and Davidar 2001). On the other hand, micro seeds such as Maesa. indica, Ficus sp, small-sized seeds such as Symlocos cochinchinensis, Viburnum punctatum and medium-sized ones such as Litsea wightiana, Elaeocarpus munronii and others which are dispersed by birds (bulbuls) and brown palm civets could easily negate this distance effect by employing the dual dispersal strategy. Dual dispersers such as bird-mammal (BM) do not appear to be constrained by distance from the forest both in CHM and NTK. This can be expected as bird dispersed species may disperse seeds in the plantations closer to the forest as seen above, but non-volant species such as civets or bear, which traverse through the plantations, can disperse the seeds deep inside the plantations. So, dispersal limitation could also be a function of the disperser assemblage involved in the dispersal of species.

Trees and shrubs especially with seeds larger than 0.5 cm (i.e., medium-size seeds), which mostly belonged to early-succession species such as S. cochinchinensis, E. munronii, E. serratus and many Lauraceae species, and understorey species of Psychotria sp. depended on frugivores and therefore dispersal was influenced by distance from forests. However, in case of herbs no such effect was seen. This may be because herbs experience passive dispersal either by ballistic/dehiscing methods and do not require animal vectors. An earlier study which compared herbs in reclaimed mine sites to control sites showed no difference in species richness (Holl 2002). Further, seeds of herb species are of very small size (< 0.5 cm), and could be dispersed by invertebrates such as ants (myrmecochory), by epizoochory (transported externally by animals that can have a variety of adaptations for dispersal, including adhesive mucus, and a variety of hooks), spines and barbs (Sorensen 1986); also by runoff water in terrain having steep slopes (hydrochory) (Howe and Smallwood 1982) or by wind (see Figure 2.6). This could be the reason why herbs did not show significant distance-related dispersal difference in forests.
and plantations, except in CHM where species richness declined. This may be due to the over grown invasive species in CHM.

**Elevation and forest colonisation**

Elevation difference between the two plantations was about 300 m and only 7% of the native species were shared between the plantations, whereas 31% of species was shared between the two elevation forests (Figure 2.3). This is because a large proportion of species was unique to each elevation owing to the transitional ecotone effect caused by sharp bioclimatic gradients (Pascal and Pelissier 1996; Pascal and Ramesh 1987). An earlier study by Ganesh et al. (1996) reported a similar pattern caused by a small change in elevation, which influenced the species composition, within the mid-elevation wet evergreen forests of KMTR.

Frugivore composition also changes due to elevation change. Earlier studies elsewhere emphasised that changes in the vegetation pattern may change species richness and abundance of frugivores (Herrera 1984). In this study, very sharp changes in elevation (i.e., 300 ± 50 m) accounted for about 58% of species common between the two plantations and 40% common species between the forests of CHM and NTK (Figure 2.11). Though frugivore richness and composition only changed marginally between plantations (Appendix 2.2a), the change in frugivore abundance was high in plantations at higher elevations. The reason behind such changes could be the availability of food resources (Loiselle and Blake 1991; Herrera 1984). In NTK, Black bulbul was the only dominant frugivore which was highly mobile and foraged in flocks, which accounted for its abundance. It preferred canopy trees and frequented mass-fruiting species such as *E. munronii*, *L. wightiana* and *Persea macrantha*, across a large landscape, and was therefore seasonal.

The higher elevation plantation at NTK also recorded higher seed input in all the distances compared to lower elevation CHM plantations, though one would expect more seed input from CHM due to the transitional ecotone of deciduous to evergreen species.
present in the surrounding forest. The reason for lack of such differences could be the absence of mass-fruiting species in CHM, unlike in NTK, where *E. munroni* and *S. cochinchinensis* produced large number of fruits. This could be a reason for presence of lesser number of *Hypsipetes leucocephalus* than *Pycnonotus jocosus* in CHM. In CHM, the undulating terrain with forest adjacent to open grassland could be less attractive to many forest frugivores.

**Abandonment and forest colonisation**

Species richness and seed diversity of seed bank also depended upon the temporal pattern of land abandonment. Currently managed plantations in KMTR received 11% of species and 2% of seeds from the forest (Table 2.7). Abandoned plantations at NTK and CHM received 60% and 66% of species, and 51% and 50% of seed density respectively. Such differences between managed and abandoned plantations were due to mass fruiting of *E. munronii* along the edge and these were not dispersed much into the managed plantations, and moreover this species was less abundant in forests near abandoned plantations. After 17 years, the abandoned plantations appear to have received good number of seeds from the forests. A study from Costa Rica has shown that seed density varies with the years of abandonment and time depending upon successional changes in the vegetation (Young et al. 1987).

**Table 2.7. Species richness (m⁻²) and seed density (m⁻²) within managed and abandoned tea plantation and adjacent forests.** *(Chetana and Ganesh 2012).*

<table>
<thead>
<tr>
<th>Plantation plot (m⁻²)</th>
<th>Species richness</th>
<th>Seed density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forest</td>
<td>Tea</td>
</tr>
<tr>
<td>Managed @</td>
<td>3.07 ± 0.12</td>
<td>0.39 ± 0.32</td>
</tr>
<tr>
<td>CHM</td>
<td>1.78 ± 0.08</td>
<td>0.99 ± 0.06</td>
</tr>
<tr>
<td>NTK</td>
<td>2.35 ± 0.08</td>
<td>0.79 ± 0.05</td>
</tr>
</tbody>
</table>

Although density of seeds in abandoned plantations may be “increasingly” similar to that of the species in the forests, their compositions was only 18-34% similar with the forest
(Figure 2.3); which indicates that there is more to seed recovery than just seed density. The plantations were abundant in early succession species such as Osyris arborea, and V. punctatum at lower elevations; and M. indica, V. punctatum, S. cochinchinensis and E. serratus at higher elevations and late successional species were missing which could be a reason for such differences in composition since late successional species form a major component of primary forests.

Studies on abandoned fields elsewhere show that remnant/perches negate the seed input limitations caused by distance from the forest (Zanini and Ganade 2005; Holl 2002; Holl et al. 2000; Galindo-González et al. 2000; Holl et al. 2000; Duncan and Chapman 1999; Holl 1998). An abandoned pasture in Costa Rica showed that trees with perches enhance the seed input compared to the ones that do not have perches (Holl 1998). Similarly, within abandoned ‘shade and sun’ coffee plantations, seed input was facilitated by shade or remnant perches (Marcano-Vega et al. 2002). The tea plantations though abandoned for 17 years without any management interventions, having good seed sources from the surrounding forest and a fair amount of volant and non-volant frugivores but still only 51-65% of the forest plant species were recorded within the plantations, all of which were early successional species; and large-seeded late successional species were yet to reach the plantations. This indicates that not only large frugivore dispersed species are limited, but even when few such species do reach the plantation, habitat suitability and conditions may not be conducive for establishment (see Chapter 3). In general distance from forests in combination with functional traits of the seeds arriving at the plantations are critical how abandoned areas recover into natural forests.

References


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