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Recruitment of saplings in active tea plantations of the Nilgiri Mountains: Implications for restoration ecology

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Abstract: Restoration and reforestation of montane forests (sholas) constitute a major challenge in open, degraded and plantation areas in the upper Nilgiri Mountains, southern India. Recent studies have reported that exotic and tea plantations enhance natural regeneration of native species. In this study, we selected three treatments (thinned, unthinned and control) and established four 40 × 40 m (0.16 ha) plots as follows: one in a Thinned treatment (TP), two in an Unthinned treatment (UNT1 and UNT2) and one in a control treatment. The thinned and unthinned treatments were established in tea plantations while the control treatment was in a nearby shola nature reserve. Overall, a total of 635 sapling individuals belonging to 38 species, 31 genera and 22 families were recovered in all four plots. Species richness and stem density were lower while mean sapling height was higher in the thinned and unthinned treatments than in the control. The thinned and unthinned treatments shared only eight (21 %) species, indicating low spatial turnover. *Berberis tinctoria* Lesch. *Daphniphyllum neilgherrense* (Wight) K. Rosenthal., *Neolitsea cassia* (L.) Kosterm and *Ligustrum perrottetii* A. DC. were the most dominant species in the thinned and unthinned treatments. *Litsea glabrata* Gamble was the most dominant species in the control plot. Among the pioneers, most species (74 %) were shade tolerant while 26 % of the species were light tolerant. Bird dispersal (39 ± 12.02 %) was significantly higher than Mammal/Anemochory/ Autochory. Random spatial distribution (58 %) was higher than clumped distribution (48 %) but the difference was not significant. Species diversity was significantly correlated among treatment plots. We, therefore, concluded that proper management of tea plantations facilitates regeneration of woody species of sholas and good recruitment of their seedlings into saplings were influenced by biotic dispersal. In addition, our results suggest that shola woody saplings growing in active tea plantations might be early successional species, thus making these species more effective for restoration of shola ecosystems.

Resumen: La restauración y la reforestación de los bosques montanos (sholas) son un gran reto en áreas degradadas y de plantación en las Montañas Nilgiri, sur de la India. Estudios recientes reportaron que las plantaciones de té y de especies exóticas promueven la regeneración natural de especies nativas. En este estudio seleccionamos tres tratamientos (con y sin aclareo, y control) y establecimos cuatro parcelas de 40 × 40 m (0.16 ha) de esta manera: una en un tratamiento con aclareo (TP), dos en un tratamiento sin aclareo (UNT1 y UNT2) y una con el

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control. Los tratamientos con y sin aclareo se establecieron en plantaciones de té, y que el tratamiento control lo fue en una reserva natural cercana de shola. En las cuatro parcelas se registraron en total 635 individuos de brinzales de 38 especies, 31 géneros y 22 familias. La riqueza de especies y la densidad de tallos fueron menores, mientras que la altura promedio de los brinzales fue mayor en los tratamientos con y sin aclareo que en el control. Sólo se compartieron ocho especies (21 %) entre los tratamientos con y sin aclareo, lo que indica un recambio espacial bajo. *Berberis tinctoria* Lesch., *Daphniphyllum neilgherrense* (Wight) K. Rosenthal, *Neolitsea cassia* (L.) Kosterm. y *Ligustrum perrottetii* A. DC. fueron las más dominantes en los tratamientos con y sin aclareo. Litsea glabrata Gamble fue la especie dominante en la parcela control. Entre las pioneras, la mayoría de las especies (74 %) fueron tolerantes a la sombra, mientras que 26 % de ellas fueron tolerantes a la luz. La dispersión por aves (39 ± 12.02 %) fue significativamente más alta que la mamalocoria/anemocoria/autocoria. La distribución espacial aleatoria (58 %) fue mayor que la distribución agregada (48 %), pero la diferencia no fue significativa. La diversidad de especies estuvo significativamente correlacionada entre las parcelas de los tratamientos. Concluimos que el manejo adecuado de las plantaciones de té facilita la regeneración de especies leñosas de los sholas y que el buen reclutamiento de sus plántulas a la etapa de brinzales estuvo influenciado por la dispersión biótica. Además, los resultados sugieren que la buena regeneración natural de especies leñosas características de las sholas y la colonización de sus brinzales en plantaciones activas de té hacen de ellas especies ideales pioneras o sucesionales tempranas efectivas para la restauración de los ecosistemas de té.

Resumo: A restauração e reflorestamento de florestas de altitude (sholas) constituem um grande desafio em áreas abertas, degradadas e de plantações nas zonas cimeiras das montanhas Nilgiri, sul da Índia. Estudos recentes têm relatado que as plantações exóticas e de chá incentivam a regeneração natural de espécies nativas. Neste estudo, foram selecionados três tratamentos (desbastado, não desbastados e controlo) e estabelecidas quatro parcelas de 40 × 40 m (0,16 ha) da seguinte forma: uma num tratamento desbastado (TP), dois num tratamento não desbastado (UNT1 e UNT2) e um num tratamento de controlo. Os tratamentos desbastados e não desbastados foram estabelecidos em plantações de chá, enquanto que o tratamento controle foi instalado numa shola de uma reserva natural próxima. No geral, um total de 635 plântulas pertencentes a 38 espécies, 31 géneros e 22 famílias foram assinaladas em todas as quatro parcelas. A riqueza de espécies e densidade dos troncos foram menores, enquanto que a altura média dasplântulas foi maior nos tratamentos desbastados e não desbastados do que no controlo. Os tratamentos desbastados e não desbastados partilham apenas oito espécies (21 %), indicando baixa rotatividade espacial. A *Berberis tinctoria* Lesch., *Daphniphyllum neilgherrense* (Wight) K. Rosenthal., *Neolitsea cassia* (L.) Kosterm. e *Ligustrum perrottetii* A. DC. foram as espécies mais dominantes nos tratamentos desbastados e não desbastados. A Litseaglabrata Gamble foi a espécie mais dominante na parcela de controlo. Entre as pioneiras, a maioria das espécies (74 %) eram tolerantes ao sombreamento, enquanto que 26 % das espécies eram tolerantes à luz. A dispersão avícola (39 ± 12,02 %) foi significativamente maior do que a revelada para os mamíferos/ anemocórica / autocórica. A distribuição espacial aleatória (58 %) foi maior do que a distribuição agregada (48 %), mas a diferença não foi significativa. A diversidade de espécies estava significativamente correlacionada entre parcelas de tratamento. Por isso, concluiu-se que a gestão adequada de plantações de chá facilita a regeneração de espécies lenhosas de sholas e o bom recrutamento de suas plântulas em nascedio foram influenciadas pela dispersão biótica. Além disso, os nossos resultados sugerem que as plantas de espécies lenhosas nas shola,crescendo em plantações ativas de chá podem ser as espécies pioneiras da sucessão, tornando-as assim mais eficazes para a restauração dos ecossistemas de té.

Key words: Human modified landscape, Nilgiri Mountains, restoration, shade-tolerant species, shola forest, spatial distribution.

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Introduction

Increasing land-use intensity modifies native landscapes and causes potential biodiversity loss (Fischer & Lindenmayer 2007; Laurance *et al.* 2014). The most important land-use changes include agricultural expansion, exotic tree plantation, and the exploitation of timber and non-timber forest products (NTFP) (Norton *et al.* 2013; Laurance *et al.* 2014). These anthropogenic activities heavily reduce native forest cover and landscape connectivity leading to increased spatial isolation of remnant forest patches. In Asia and the Pacific Region, rate of forest loss was 0.7 million haper year during the 1990s (FAO 2011; http://www.fao.org/docrep/013/i2000e/i2000e.pdf, ISBN 978-92-5-106927-1). Though 1.4 million ha of forest have been gained annually in the last decade, some countries within the region continuously experience high rates of deforestation (FAO 2011).

India is one of the countries in South Asia highly affected by land use and land cover changes (Davidar *et al.* 2007a; Sodhi *et al.* 2010). In the Upper Nilgiris of the Western Ghats, biodiversity-rich native forest-grassland-swamps have been converted into other land use types, particularly monoculture plantations (acacia and tea) seriously modifying the original landscapes (Davidar *et al.* 2007a; Puyravaud *et al.* 2012; WGEEP 2011). Large-scale tea cultivation has received increased attention from local inhabitants who mainly exploit the mid- and high-elevation regions of the Nilgiri Mountains. These tea plantations have serious negative consequences on the natural ecosystems and have reduced the extent, structure, and productivity of native primary and secondary forests (Kumar 1993; Mohandass *et al.* 2008).

Since human-modified landscapes and land-use changes promote biodiversity loss that could result in massive species extinctions (Cardillo *et al.* 2006; Laurance *et al.* 2014; Lee & Jetz 2008; Sodhi *et al.* 2010), urgent restoration and reforestation of these landscapes is crucial to avert these negative consequences. In South Asia, restoration of degraded ecosystems has been an important component of forest management and conservation since the early 1980s (Sayer *et al.* 2004). Despite claims that restoration often contradicts efforts to improve human livelihoods due to increasing agricultural expansion and environmental alterations (Laurance *et al.* 2014). Thus, forest restoration may influence less agricultural production that affects human revenue resource and rehabilitation (Lamb *et al.* 2005). However, restoration efforts give people's social respect, cultural values (Lamb *et al.* 2005; Norton *et al.* 2013) and also aids to protect from climate-change impacts on biodiversity declines (Jørgensen *et al.* 2014). Finally, it remains the most effective tool for the sustainable forest management and conservation of native flora and fauna (Lamb *et al.* 1997; Raman & Mudappa 2003). The present study focuses on the recovery of native plant species in tea plantations and the implications of this recovery for restoration and reforestation of native forests.

In the Western Ghats of India, montane evergreen forests locally called 'sholas' (> 1500 m) naturally occur in discrete patches, usually confined to sheltered valleys, hollows and depressions, and are surrounded by grasslands. They are characterized by stunted short-boled evergreen trees that are unable to regenerate in open areas due to lack of tolerance to fire and frost (Meher-Homji 1984; Mohandass & Davidar 2009). These forests occur extensively at higher elevations in the Nilgiri and Palni hills of southern India. Due to agricultural expansion, conversion into monoculture plantations, livestock grazing and rural development, a large proportion of this forest type has been degraded and destroyed (Kumar 1993; Puyravaud *et al.* 2012). An estimated half of the sholas in the Nilgiris has been destroyed since 1849 and the current area of sholas is only about 4,225 ha (Kumar 1993; Mohandass & Davidar 2009). A reasonable area of the forests has been converted into exotic tree plantations (e.g. *Acacia*, *Eucalyptus*) and monoculture agriculture (especially tea), with nearly 70 % of the total cultivated land covering an area of over 45,974 ha (Kumar 1993). Thus, restoration and reforestation of shola forest effort would be fundamental strategy for increasing forest area that can prevent species extinction and the maintenance of species diversity for the purpose of conservation of shola forest ecosystems.

Tea plantations constitute a good milieu for seed dispersal, germination and recruitment of native plant species because they offer suitable natural conditions (e.g. shade and moisture) for regeneration (Chetana & Ganesh 2012; Sreekar *et al.* 2013). Most shola species are shade tolerant while a few are light-demanding species (Meher-Homji 1967). Close canopy conditions are more important for seed germination while open canopy conditions are more important for seedling growth and survival. Many studies suggest that exotic tree plantations in degraded areas can stimulate natural

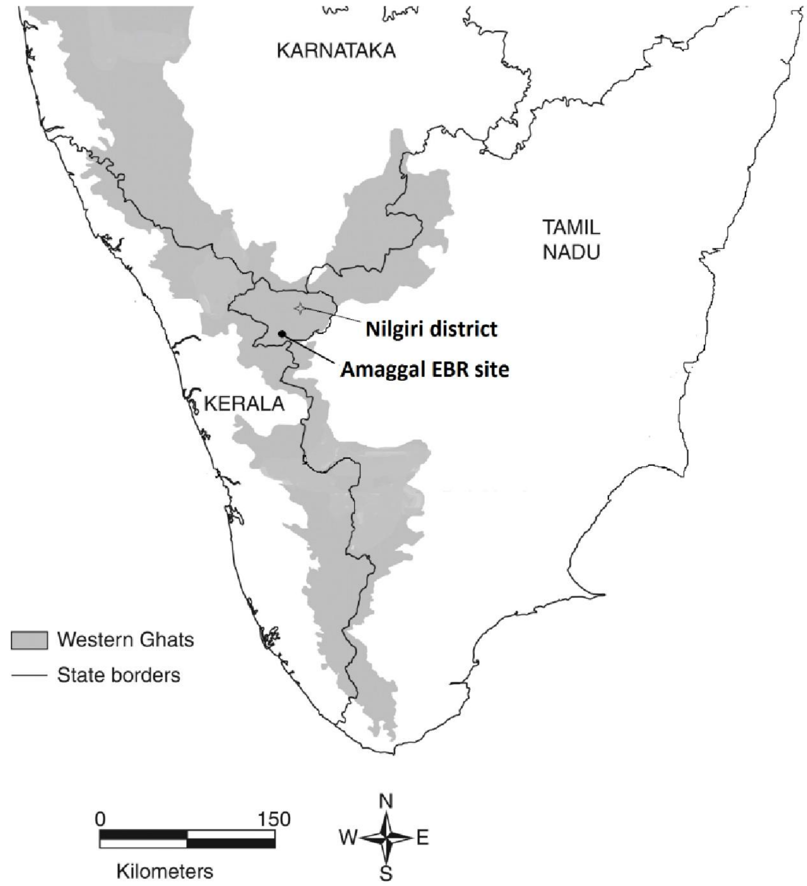

Fig. 1. A map showing that study area (Amaggal) and Edhkwehlynawd Botanical Refuge (EBR) restored site located in the southern Nilgiri District, southern India.

recruitment of native tree species (Brockerhoff *et al.* 2008 Carnus *et al.* 2006; Selwyn & Ganesan 2006; Zanne & Chapman 2001). A possible explanation might be because exotic plantations allow direct light penetration to the forest floor that enhances growth and survival of native tree seedlings and saplings (Caldwell & Pearcy 1994; Selwyn & Ganesan 2006). Another potential method used to restore native flora is Assisted Natural Regeneration (ANR). It is a simple, cost-effective forest restoration technique that makes it possible to recover biodiversity in tropical rainforests (Ganz & Durst 2003; Shono *et al.* 2007). ANR accelerate species succession, reduce weed competition, prevent disturbance, provide a suitable microclimate, and enhance seed dispersal by birds and animals (Shono *et al.* 2007).

This study was conducted in active tea plantation which was owned for restoration and reforestation processes of tropical montane evergreen forest (shola) woody species of the upper Nilgiri Mountains. In this study, active tea plantation regarded as growth success of each tea plant flourishes young leaves and harvesting the fresh leaves by local farmers monthly once or twice. We found that ANR by active tea plantation supports much native regeneration. The earlier study reported that forest sapling species those first recruiting or regenerating under exotic plantation by colonization or through natural dispersal processes were considered as pioneer (Selwyn & Ganesan 2006). For this study, we treated the species that are regenerating under active plantation was considered as pioneer woody species. However, the assessment of diversity and density of woody species in active plantations within the studied regions through quantative methods has not been carried out. The specific objectives of this study were, therefore, to: (1) determine the number of native sapling species in active tea plantations; (2) compare species richness, stem density and height of the native sapling species among different treatments; (3) understand the spatial pattern of the native sapling species; and (4) examine how diversity of native sapling species is correlated among treatments.

Materials and methods

Study site

The experimental study was conducted in Edhkwehlynawd Botanical Refuge (EBR) site. EBR is a non-profit organization trust established in 2003 (www.ebr.org.in). It is located adjacent to the Amaggal nature reserve forest, about 40 km southwest of the Ootacamund Headquarters of the Nilgiri District, southern India (Fig. 1). It lies between 11° 25'. 041 N and 076° 61'.652 E with an elevation of ~ 2033 m. The bedrock is composed of gneisses, charnockites, and schists (von Lengerke 1977). The parent rock is gneiss and the soils contain large amounts of humus in the top layers (Meher-Homji 1967). The ferrallitic humiferous soil, mostly black in colour has high organic matter content (Blasco 1970) and andisols (Caner *et al.* 2007). The climate is cold, wet, and windy during the monsoon months, with temperatures ranging from below 0 to 23 ºC. Frost is frequent from December to February. The study site receives rainfall from both the South West (SW) and North East (NE) monsoons. The mean annual rainfall recorded at Korakundah Tea Estate, located about 5 km away from the study site, was 2108 mm (1996 - 2007). The dry season length (5 months) was calculated as the sequential number of months with rainfall < 100 mm (Mohandass 2007). The Nilgiri hills comprise of five indigenous tribes namely Todas, Kurumbas, Kotas, Irulas and Cholanayakas.

Methods

Edhkwehlynawd Botanical Refuge (EBR) Centre Trust purchased a tea plantation through the IUCN project during March 2007 - May 2007 for conservation and restoration of sholas. The cultivation of large-scale tea in this area began as early as the 1940s. Since then, local farmers have regularly harvested tea leaves, applying compost, pesticides and weeding as the main management techniques in the tea plantations. However, the tea plantations purchased by EBR were not properly managed during the first five years except the Unthinned plot 1 (UTP1). The total area of land purchased was about 13.13 acres (5.9 ha). However, total area occupied by tea plantations was only about 40 ha, the rest being private property. The EBR site was purchased from three scattered plots with areas that vary between 0.53 acre (0.214 ha) and 4.0 acre (1.62 ha). The total area of purchased land was fully covered with tea and silver oak plantations, whereas adjacent surroundings were *Acacia dealbata* Link., (wattle) and *Eucalyptus globulus* Labill., (blue gum) plantations.

The treatment plots were established from September 2007 - May 2008 in tea plantations. Among these EBR plots, some areas had sparsely planted tea, other areas are covered with densely planted tea for several years. Thus, we categorized sparsely and densely planted tea areas into Thinned (TP) and Unthinned (UTP) plots, respectively. We selected one TP, two UTP (UTP1 and UTP2) and one control plots for this study. The control plot was established within the shola nature reserve (henceforth Shola Plot; SP) and is located close to the experimental tea plantation. A detailed description of the four treatment plots is given in Table 1.

In each treatment, we laid a 40 × 40 m (0.16 ha) plot and subdivided it into four 10 × 10 m subplots. We surveyed all shola sapling species that were ≥ 0.1 m tall. All saplings within this target height class were marked, tagged with sequential aluminum number tags and identified to species level. In all plots, the plants individual height ≥ 0.1 m and ≤ 1.5 m were considered as saplings' for this study includes control plot. The height of each individual sapling was measured using an elastic tape.

Voucher specimens of all sampled saplings were collected and later identified to species level (Fyson 1986; Matthew 1999). The taxonomic ranks (species, genus and family) of all species were, then, determined following the APG III Classification (Bremer *et al.* 2009).

Shola species have been shown to respond differentially to shade and light conditions (Meher-Homji 1984), thus, we recorded growth response of each individual. Species that are found under tea shade were classified as shade tolerant while species that are found in both shade and light conditions were classified as light tolerant.

Dispersal modes were classified based on fruit types (van der Pijl 1982), and included: bird, bird/mammal, mammal, anemochory (air-borne) and autochory (explosive) (Selwyn & Ganesan 2006). Mammals were identified by direct field observations; Sloth Bear (*Mlursus ursinus*) and Nilgiri Langur (*Trachypithecus johnii*) were recorded as the main mammals.

Table 1. Detailed description and management practices in the treatment plots within the Edhkwehlynawd Botanical Refuge site.

Plots	Description and Management
Thinned plot (TP)	It was considered as the treatment with sparse tea plantation for 10 years from the date of purchase. The distance between each tea plant was ~ 2 to 3 meters. TP receives more light than Unthinned plots under natural conditions. It is surrounded by wattle plantations and illuminated by direct morning sunshine. The slope and aspect are in the south-west direction. The distance between the Thinned and Unthinned plots was ~ 1 km, whereas the distance between the thinned and control plot was 500 m.
Unthinned plot (UTP1)	It was considered as the treatment with dense tea plantation and harvesting of tea leaves have occurred for more than 20 years prior to the date of purchase. The distance between each tea plant is < 1 m. It receives less light than the thinned treatment and more light than control plot (SP). It is partially surrounded by wattle plantations and shola forest fringes. The slope and aspect face towards the south-east direction. Tea leaves harvesting and weed management/removal by local people farmers is frequent.
Unthinned plot (UTP2)	It was very close to UTP1 with a distance was about 100 m apart. The distance between this plot and the control plot was ~ 1.2 km. It has densely covered tea plants with same management as in UTP1. However, farmers have been harvesting tea leaves for more than 20 years, but with poor weed management during the last 5 years from the date of land purchase. It is surrounded by shola forest fringes and the slope and aspect are facing towards south-east direction.
Control or Shola plot (SP)	Sampling was undertaken from nature reserve shola forest with same height class as treatment plots. Obviously, SP receives lesser light than the other treatments plots because of its closed canopy. It was relatively undisturbed and slope and aspect are face towards the north-west direction. It is surrounded by exotic plantations such as wattle and eucalyptus.

Soil analyses

Soil samples were collected from all four treatment plots to understand the basic soil composition, however, we did not replicate the soil sampling due to infeasibility of carrying more soil samples with the permission of forest department, since EBR has not owned any laboratory infra-structure in the field station. Moreover, our plots were larger in sampling size (0.16 ha) and have not contain many replicated plots for sapling collection (only four plots). Soil was collected from three soil depths in all four plots as follows; depth 1 (0-20 cm), depth 2 (20-40 cm) and depth 3 (40-60 cm) and analyzed for soil variables, namely available Nitrogen (N), Phosphorus (P), Potassium (K), Organic content (OC) and soil electrical conductivity (EC dSm^{-1}). All soil analyses were done in the Tamilnadu Agricultural Department, Ootacamund, India.

Data analyses

All identified sapling species and individuals from each plot were summed-up.

Fisher's alpha (a measure of diversity) was calculated using the following formula: S/N = (1-x)/x (-ln (1-x), where, S is species number and N is total number of individuals (Condit *et al.* 1998; Fisher *et al.* 1943; Mohandass & Davidar 2009).

Shannon diversity index was calculated using the formula $H' = -\Sigma p_i \ln pi$, where, pi is the proportional abundance of the i^{th} species (ni/N).

Simpson's index was calculated using the formula $D = \Sigma (n_i (n_i\text{-}1)) / (N (N\text{-}1))$, where, n_i is the number of individuals in the i^{th} species and N is the total number of individuals.

The index of dominance (C) of the community was calculated using the formula $1 = [(n_i/N)2]$, where, 1 is the index of dominance, n_i is the number of individuals in the i^{th} species and N is the total number of individuals.

Pielou's evenness index was calculated using the formula: $J^1 = H^1/H^1max$ where, H^1 is the number derived from the Shannon diversity and H^1max is the maximum value of H^1.

All indices were calculated following Magurran

(2004) using the PAST statistical program (version 2). Percentage of species richness and sapling density was calculated from each plot. Mean height of saplings in each plot was analyzed by one-sample t-test. (Pagano 1990). The sapling species were arranged in descending order based on sapling abundance. A Kolmogorv-Smirnov test for normality was used to see whether the distribution differed significantly from log normal.

The frequency of distribution of each species was calculated across the four plots.

Mean soil variables of each plot were calculated and compared by one-sample t-test to test for significant differences among treatment plots. Percentage of life-form and growth response for each species were tested by chi-square test. Kruskal-Wallis chi-square test was used to compare different dispersal agents. Spearman rank correlation was used to test the species diversity relationship among treatments. All above statistical analyses were performed using the PAST Statistical Program (version 2).

To understand sapling species similarity among the four treatments, we used Sørenson similarity index. Distance matrix and group average clustering (UPGMA) were used to calculate the differences in species similarity. These analyses were performed in R version 3.01 (R Development Core Team 2013).

To understand the spatial distribution we computed the proportion of sapling abundance in each plot using the Bio-Diversity Program (version 2).

Results

Richness, density and diversity of saplings

A total of 625 individuals of saplings (≥ 0.1 m to ≤ 1.5 m high) of 38 woody species belonging to 31 genera and 22 families were recorded in the four 0.16 ha plots. Species richness ranged from 12 to 24, and number of individuals ranged from 68 to 355 per treatment plot. Dominance index was higher in TP followed by SP, but similar in UTP1 and UTP2. Shannon index ranged from 1.93 to 2.46 while Simpson index ranged from 0.80 to 0.89. However, both indices were higher in UTPI and UTP2 than in TP and SP plots. Species evenness was similar in TP, UTP1 and UTP2, but lower in SP (Table 2). Total species richness was lowest (33 %) in TP and highest (67 %) in SP. Total stem density was lowest in UTP1 (11 %) and highest in SP plot (57 %). Mean height (cm) was highest in UTPI (119.9 ± 4.46) followed by UTP2 (87.7 ± 3.63) and TP (68.7 ± 4.46), and was lowest in SP (17.09 ± 0.46). Nevertheless, mean plant height differed significantly among plots (*t-test* $= 4.19$, $N = 4$, $P < 0.03$). It indicates, sapling species height was significantly taller in the three treatments than in the control (SP).

Species-area curve

In all plots, the number of sapling species increased gradually up to 0.1 ha and levelled off. In the three plots (TP, UTP1 and UTP2), the cumulative number of species reached an asymptote from 0.14 to 0.16 ha (Fig. 2). However, in the control plot, cumulative number of species did not reach an asymptote even at 0.16 ha. However, 80 % of the sapling species were sampled within the 0.1 ha quadrat in each of the four treatment plots (Fig. 2).

Species abundance distribution

Among the four plots, the sapling abundance distribution differed significantly from a log normal distribution in UTP2 and SP plots (Kolmogorov-Smirnov $(Z) = 1.37$, $P < 0.05$ and $Z = 1.52$, $P < 0.01$, respectively). Surprisingly, sapling abundance distribution in TP and UTP1 plots did not differ significantly from a log normal distribution (K-S $(Z) = 1.01$, $P > 0.05$ and $Z = 1.11$, $P > 0.05$). The frequency of distribution of saplings in the four plots was unimodal. It indicates that the frequency of majority of species distribution exhibited less than 10 sapling individuals, and a few species had > 10 sapling individuals in each plot (Fig. 3).

Species and family composition of saplings

The most abundant species in the four treatment plots were *Litsea glabrata* Hook.f. (17 %), *Cinnamomum cassia* (L.) J. Presl. (14 %), *Ligustrum perrottetii* A. DC. (13 %) and *Berberis tinctoria* Lesch. (10 %). In the TP plot, *B. tinctoria* was highly abundant followed by *Elaeagnus conferta* Roxb., *Maesa indica* (Roxb.) A. DC. and *Daphniphyllum neilgherrense* (Wight) K. Rosenthal. In the UTP1 plot, *B. tinctoria* and *M. indica* were the most abundant and in UTP2 plot, *B. tinctoria* and *Rhamnus wightii* Wight & Arn. were highly abundant. *Litsea glabrata*, *C. cassia* and *D. neilgherrense* were most abundant in the SP plot (Appendix Table 1). Based on tree and shrub abundance, dominant families were Lauraceae (32 %),

Table 2. Summary of pioneer sapling species richness, number of genera, number of family, stem density, Dominance index, Shannon index value, Simpson index value, Fisher's alpha and Evenness among different treatments in the Amaggal site, Nilgiri Mountains. TP = thinned plot, UTP1 and 2 = unthinned plot, SP = control plot. TP and UTP1 and 2 were in tea plantations while SP was in a nature reserve (shola forest).

Treat-ment plots (0.16 ha)	Species rich-ness	Numbe of genera	Number of family	Number of stem individuals	Mean height (cm)	Domi-nance (D)	Shannon (H)	Simpson (1-D)	Fishers' α	Evenness (e^H/S)
TP	12	12	11	100	69	0.20	1.93	0.80	3.56	0.57
UTP1	18	18	16	68	119	0.11	2.46	0.89	7.99	0.65
UTP2	19	19	15	102	88	0.11	2.45	0.89	6.88	0.61
SP	24	21	16	355	17	0.15	2.23	0.85	5.81	0.39

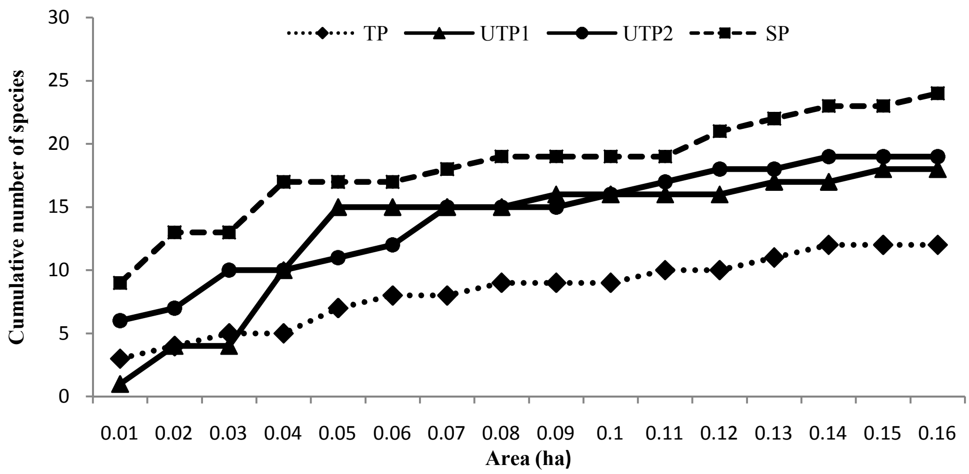

Fig. 2. Species - area curves for the four treatment plots, namely TP, UTP1 and UTP2 in active tea plantations and control (SP).

Euphorbiaceae (13 %), Berberidaceae (10 %), Canna-banaceae (6 %). Elaeagnaceae (5 %) and Rham-naceae (4 %). In terms of species composition, Lauraceae (13 %) and Rubiaceae (13 %) were the most dominant families among the four plots.

Species similarity

Five (14 %) species were shared among four plots. Eight (21 %) of the species were shared among three treatments except the control (SP). However, species similarity was low among the four plots, but the three treatments, excluding SP, were similar in species composition. The Sørenson similarity index showed similarity was higher between treatment plots. However, species similarity was lower in SP plot as compared with three treatment plots (Table 3).

Differences of soil variables among treatment plots

Across the four plots, all soil variables showed significant differences among treatments (Table 4). Mean soil organic content (%) ranged from 0.49 to 0.99, with SP showing higher organic content than

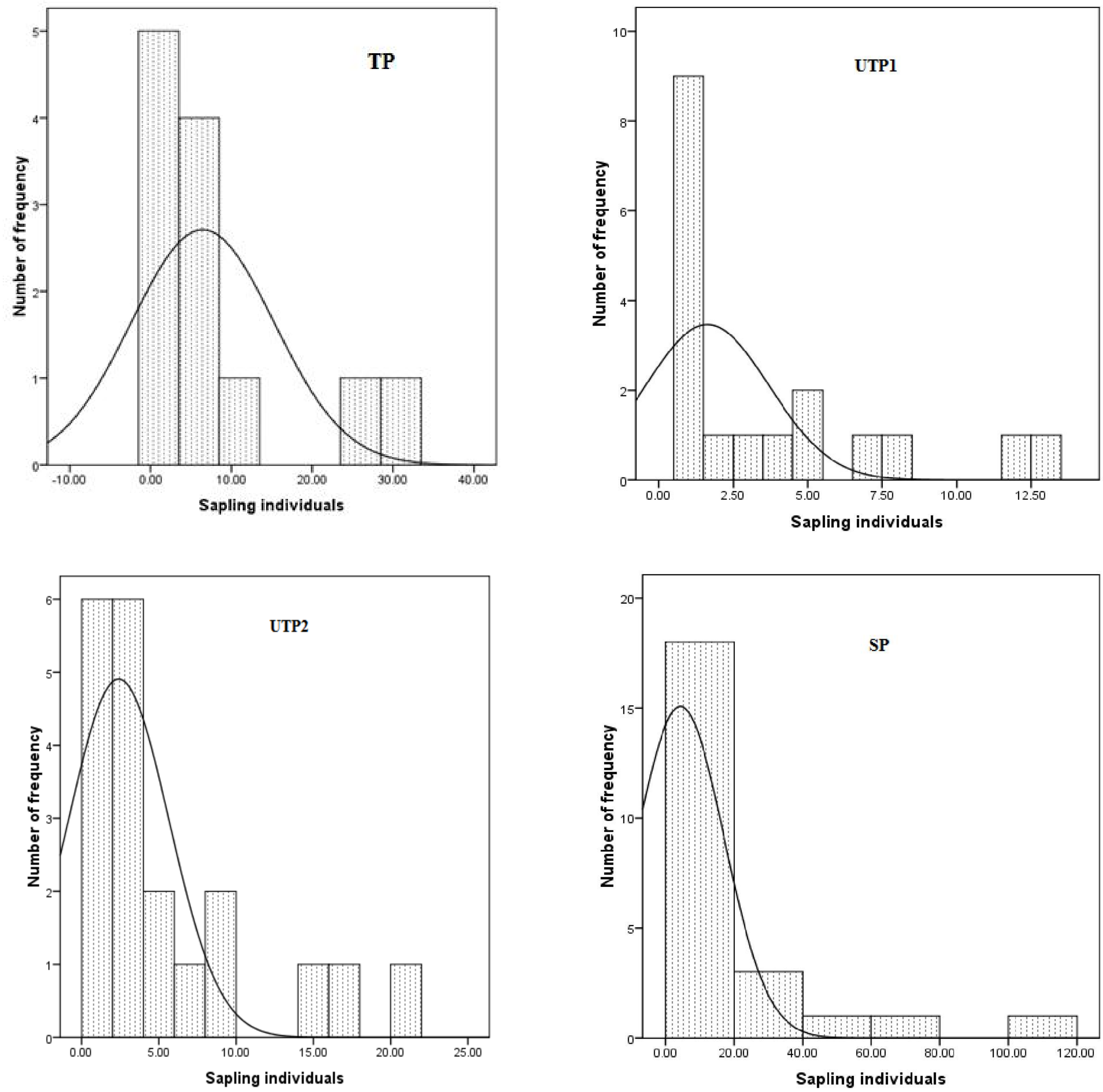

Fig. 3. Frequency of distribution of species abundance among four treatments. A Kolmogorov-Smirnov test was used to assess for normal distribution.

Table 3. Sørenson similarity index for pairs of treatment plots showing proportion of similarity in species composition and abundance.

	TP	UTP1	UTP2
UTP1	0.5595		
UTP2	0.5148	0.2941	
SP	0.8901	0.8392	0.816193

TP, UTP1 and UTP2. Potassium (K) content was higher in TP, UTP1 and UTP2 than in SP. The mean soil pH ranged from 4.57 ± 0.03 to 5 ± 0.05 among plots (Table 4).

Life-form and growth response

The percentage of species with various life-forms varied significantly (χ^2 = 207.16, df = 6, P < 0.0001), and their stem density also varied significantly (χ^2 = 90.17, df = 6, P < 0.0001) among plots (Fig. 4a & b; Appendix Table 1). Growth response in all four plots showed that shade-tolerant species were significantly higher than

Table 4. Mean (± SE) and t-test statistics of soil variables measured in four treatment plots.

Soil variables	TP	UTP1	UTP2	SP	T-test
O.C. %	0.84 ± 0.1	0.49 ± 0.01	0.73 ± 0.02	0.99 ± 0.16	7.284*
P	9 ± 2	10.67 ± 3.1	8 ± 1.73	9 ± 2	16.58**
K	11 ± 2.3	12.3 ± 4.05	12 ± 1.73	9 ± 1	14.78**
EC (dSm^{-1})	0.05 ± 0	0.047 ± 0	0.05 ± 0	0.047 ± 0	30.79***
Soil pH	5 ± 0.05	4.57 ± 0.03	4.87 ± 0.09	4.77 ± 0.03	52.58***

O.C. = Soil organic content; P = Phosphorus; K = Potassium; EC = Electrical conductivity.
(Significant level < 0.01*, < 0.001**, < 0.0001***).

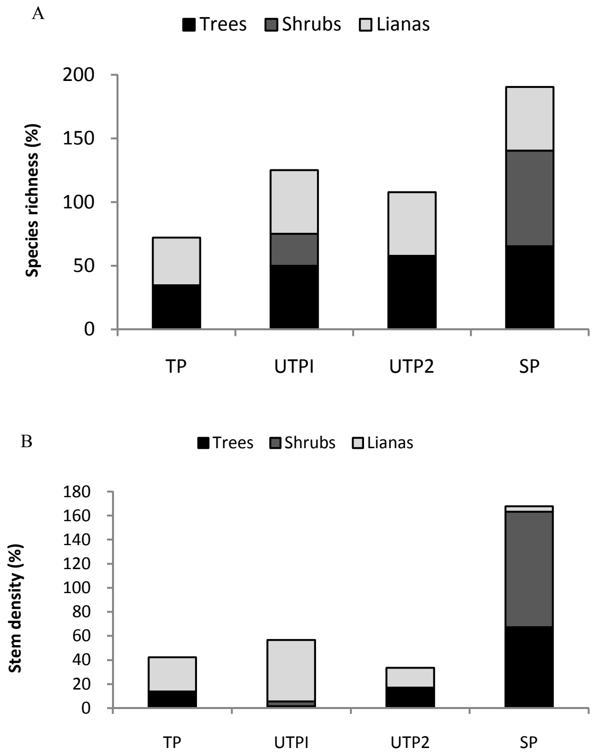

Fig. 4. (A) Percentage of species richness among life-forms and (B) Percentage of stem density among life-forms in the four treatment plots.

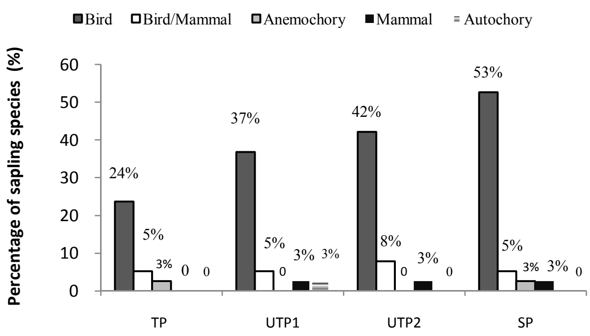

Fig. 5. Percentage of sapling species (percentage values are given above the bar) in five dispersal guilds across the treatment plots and control.

light-demanding species (χ^2 = 4.56, df = 1, P < 0.03). Kruskal-Wallis chi-squared test showed that bird dispersal was significantly higher than other dispersal types (χ^2 = 15.14, P < 0.003; Fig. 5). *Elaeocarpus hygro-philus* Kurz. and *Syzygium densiflorum* Wall. ex Wight & Arn. were dispered by mammals while *Dregea volubilis* (L.f.) Benth. ex Hook.f. was dispersed by wind.

Spatial distribution of sapling species

Random distribution (58 %) was the dominant spatial pattern followed by clumped distribution (42 %) of sapling species when all the four plots were compared. Conversely, percentage of random and clumped distribution of overall species did not differ significantly (χ^2 = 1.36, P > 0.05) among the four plots. Random distribution showed more spatial dispersion than clumped distribution in the three treatment plots (Appendix Table 1; Fig. 6).

Table 5. Spearman rank correlation-coefficient matrix of species diversity for all pairs of treatments (significant levels are indicated with asterisks).

Treatment Plots	TP	UTP1	UTP2
UTP1	0.70***		
UTP2	0.47**	0.52***	
SP	0.22	0.004*	-0.02

Matrix probabilities (P) * < 0.05, ** 0.01, ***0.001.

Correlation of species diversity

Among the four plots, species diversity was significantly correlated with the three treatment plots (Table 5). Species richness and density were signficantly correlated between thinned and unthinned plots (signficant level ranged from P < 0.05 to 0.001). It indicates that apart from the

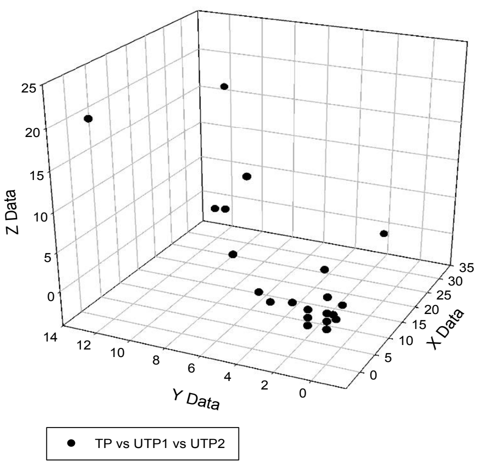

Fig. 6. Spatial pattern of sapling species distribution based on abundance among three treatments.

control plot, the other three treatment plots showed high similarity in species diversity. Moreover, it suggests that species diversity was similar among treatment plots, possibly, due to uniformity in seed dispersal.

Discussion

Our study results demonstrate that tea plantations enhance shola species regeneration through biotic dispersal-driven natural colonization. We found that most of the saplings in tea plantations were pioneer or early successional species (Fig. 7). These saplings were more diverse and rich in species composition among the treatments. However, the control plot had an equal number of pioneer and late-successional species compared to the other treatment plots. Our results show that mostly shade tolerant and light demanding sapling are contributed as pioneer species. For instance, common shade tolerant species were *L. glabrata*, *C. cassia*, *D. neilgherrense*, and *L. perrottetii*. We found few species (e.g. *B. tinctoria* and *M. indica*) were common as light-tolerant. Therefore, these shade and light tolerant species were highly contributed for sapling recruitment and germination under active tea plantation (Mohandass *pers. obs*).

Species richness and stem density were higher in the control plot than tea plantations. Two possible factors driving this pattern include the fact that the control plot had significantly higher soil organic content (Table 2) and was located within the nature reserve with little or no human disturbance. The Thinned plot (TP) had lower species richness than the Unthinned plot (UTP1 and UTP2), but both were similar in stem density. However, the Unthinned plot may recruit more sapling species under tea shade conditions. The slight variation in sapling recruitment and species composition between Thinned and Unthinned plots was mainly due to differences in light availability (Table 1). Since Thinned plots receive more light than Unthinned plots, Unthinned plots possibly recruit more saplings and show high species composition. However, UTP2 showed less number of individuals than Thinned plots. This might be due to the frequent manual removal of saplings by local tea workers who consider shola saplings as unwanted weeds. The control (SP) plot had received less light and more shade due to the influence of large tree canopy cover and dense growth in the understory levels. Generally, light levels in the tropical rainforest understory are typically low (Cunningham 1996), but the growth and survival of saplings increase with the greater light availability (Tobin & Reich 2009). Though in the control plot had a high species richness and a sapling density than treating plots due to impact of less disturbance and with the influence of neighboring diverse species composition. However, shola pioneer sapling species require more light for their survival and growth. Besides, our results showed that the mean height of sapling growth in each treatment plot was higher than control plot due to greater light availability in the active tea plantation.

Therefore, TP, UTP1 and UTP2 are more effective for regeneration of shola woody species, and this has great implications for forest restoration and reforestation. However, mean height differed significantly between control and treatment plots. The control (SP) plot showed lower mean height due to low light intensity compared to TP, UTP1 and UTP2 plots (Table 1). This indicates that seedling and sapling growth is reduced in the shaded understory compared to the increased growth in the relatively high photosynthetically active radiation in gaps (Turner 1990).

Species composition was similar among treatments with highly abundant species being *B. tinctoria, D. neilgherrense* and *M. indica*. But in the control plot, *Litsea glabra* and *Neolitsea cassia* (Lauraceae) were more common. This plant family is the most dominant in terms of species richness in high elevation sholas (Mohandass & Davidar 2009). On the other hand, dominant species in the treatment plots were mostly pioneers with high potential for shola restoration success. Three treat-

Fig. 7. (A) A view of restored plots UTP1 and UTP2 located adajcent to shola nature reserve; (B) A pioneer sapling *Berberis tinctoria* recruited under the tea plantation shade; (C) *Daphniphylum neilgherrense* was regenerating well under the tea shade condition; and (D) *Syzygium densiflorum* regenerating well under the tea shade condition and leaf flushing after grazed by Sambar deer.

ment plots were shared similar in species composition and showed a high level of species similarity. As compared to SP plot, species similarity was lower that indicates control plot had more diverse in species composition than treated plots in active plantation. Therefore, during early stage of species recruitment under tea shade showed that the level of species similarity was similar, but low diverse in species composition than SP plot due to dispersal limitation (Davidar *et al.* 2007b). The abundance of different life-forms differed significantly among treatments. Lianas were more abundant in TP and UTP1 than trees and shrubs, indicating that lianas are increasing in abundance in tea plantations due to high human disturbance. Species mostly showed random distributions, though clumped distributions were equally found among treatments. During early-succession, recruitment of sapling in sholas shows random distribution because pioneer species are likely to be common in gaps where high light favors survival (Queenborough *et al.* 2007). However, once they attain a certain height, most species tend to exhibit clumped distribution (59 %) while few exhibit random distribution (41 %) [See Mohandass (2007) for more details]. Several studies have reported a high degree of clumped distribution in tree seedlings (Gratzer *et al.* 1999; Laliberte *et al.* 2008; Paluch 2005). In this study, clumping was lower than random distribution because, generally, clumping is not related to light intensity (Szewczyk & Szwagrzyk 2010). However, spatial distribution was not significantly different among treatment plots.

Interestingly, species diversity was significantly correlated with treatment plots, suggesting that pioneer species are quite homogenous and similar in spatial distribution. It suggests that species found in active plantations belong to the species pool as nearby shola forest. Besides, our study found that a high number of pioneer species was dispersed by birds than mammals or anemochory among tea plantations. This is a common dispersal pattern among exotic plantations in the Western Ghats (Selwyn & Ganesan 2006). We, therefore, emphasize that tea plantations strongly enhance native shola species regeneration, especially pioneer species dispersed by biotic vectors. Moreover, adjacent nature reserves highly facilitate the recovery of native plant diversity in tea plantations. These findings are consistent with previous studies in the Western Ghats, which reported that tea plantations facilitate native plant regeneration through bird dispersal across adjacent nature reserves (Chetana & Ganesh 2012; Harvey 2000; Sreekar *et al.* 2013).

Our results also showed that soil variables significantly varied among treatment plots. However, soil organic matter was higher in shola nature reserve than in tea plantations (Caner *et al.* 2000, 2007). Potassium was higher in tea plantations than in the control plot, because local tea farmers regularly apply compost in their tea plantations. However, compost nutrients in the treatment plots did not influence species composition and diversity since the control plot showed high species composition and diversity than the other treatment plots. Moreover, in the treated plots of active tea plantations, saplings were managed by local farmers. Thus, we are still unclear whether compost nutrients influence shola species composition in active plantations. Hence, further experimental studies may confirm the effects of nutrient availability.

Many shola forest plantations in open areas failed due to frequent fire outbreaks, frost, grazing and exotic species invasions (Bor 1938; Meher-Homji 1967; WGEEP 2012). Most degraded lands harbor many exotic species, especially vines (*Rubus* spp.) brackens or grasses colonize and influence slow tree invasion in degraded lands (Duncan & Chapman 2003; Zanne & Chapman 2001). Although exotic shrubs (e.g. *Cestrum* spp.) often quickly invade degraded habitats, they may compete with trees for resources (e.g. light and nutrients) and slowdown forest re-growth (Holl 1998; Rogers & Hartemink 2000). For example, *Cestrum elegans* (Brongn.ex Neumann) Schltdl. *Lantana camara* L. and *Ulex europaeus* L. are extensively distributed across forest edges and degraded lands. Thus, we believe that exotic species in tea plantations would definitely hinder the recruitment and establishment of saplings. Tea plantations often support exotic species, such as *Acacia dealbata* Link., *Acacia mearnsii* De Wild., *Pteridium aqualinum* (L.) Kuhn., *Agertina adenophora* (Spreng.) R. M. King & H. Rob and *Rubus ellipticus* Sm. These are possibly affecting the survival and growth of native shola species. Therefore, for effective management, recovery and conservation of sholas, reforestation would be an important measure to control weed invasion. Direct planting of shola seedlings on grassland is likely to be unsuccessful due to insufficient nutrient availability, competition with grasses and physiological factors (Posada *et al.* 2000). Nevertheless, restoration in tea plantations would be the best and most successful plan for reforestation and recovery of shola plant communities. However, due to different elevational gradients, shola pioneer species may vary from place to place, and many of these species have Western Ghats affinities (Mohandass & Davidar 2009).

Practical implications

According to our results, we propose that natural regeneration of shola species in tea plantations is a potential and cost-effective management tool in shola forests. Therefore, proper management of exotic and invasive species in tea plantations would possibly facilitate the germination/regeneration and establishment of shola species.

In open areas, shola planting might possibly succeed under proper shade management, regular watering, composting, no grazing and weed control conditions. Moreover, species selection would be more important for planting in open areas.

Long-term restoration and land management may influence successful shola sapling regeneration. This would make it possible to re-create native vegetation such as shola-grassland ecosystems. However, unfavorable climatic factors such as frost and severe dry seasons may not affect restoration of sholas if stronger and efficient planning methods that address shola-grassland landscape issues are available.

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Appendix Table 1. Names, family, life-form, percentage abundance and spatial pattern of 38 plant species distributed across thinned, unthinned and control treatment plots within the study area. Species with < 0.05 exhibit clumped spatial distribution while species with > 0.05 exhibit random spatial distribution. TP = thinned plot, UTP1 and 2 = unthinned plot, SP = control plot. TP and UTP1 and 2 were in tea plantations while SP was in a shola forest.

Sapling names	Family	Life-form	TP (%)	UTPI (%)	UTP2 (%)	SP (%)	Mean	χ2	*P*-value	Spatial pattern
Berberis tinctoria Lesch.	Berberidaceae	Tree	33	18	16	0	15.25	36.7	< 0.0001	Clumped
Celtis timorensis Span.	Cannabaceae	Tree	1	3	2	10	9.75	80.1	< 0.0001	Clumped
Cinnamomum cassia (L.) J. Presl.	Lauraceae	Tree	8	10	9	17	21.5	101.8	< 0.0001	Clumped
Chionanthus ramiflorus Roxb.	Oleaceae	Tree	0	0	0	1	0.5	6	0.1099	Random
Connarus wightii Hook.f.	Connaraceae	Liana	0	1	0	0	0.25	3	0.39	Random
Daphniphyllum neilgherrense (Wight) K. Rosenthal	Daphniphyllaceae	Tree	1	19	20	13	20	54.3	< 0.0001	Clumped
Derris scandens (Roxb.) Benth.	Leguminosae	Liana	0	0	0	1	0.25	3	0.39	Random
Dregea volubilis (L.f.) Benth. ex Hook.f.	Apocynaceae	Liana	3	0	0	0	1	6	0.11	Random
Elaeagnus conferta Roxb.	Elaeagnaceae	Liana	26	1	2	0	7.5	61	< 0.0001	Clumped
Elaeocarpus hygrophilus Kurz.	Elaeocarpaceae	Tree	0	0	0	1	0.25	3	0.39	Random
Embelia tsjeriam-cottam (Roem. & Schult.) A. DC.	Primulaceae	Liana	0	1	0	0	0.25	3	0.39	Random
Euonymus crenulatus Wall. ex Wight & Arn.	Celastraceae	Tree	0	0	0	1	0.5	6	0.11	Random
Eurya nitida Korth.	Pentaphylacaceae	Tree	0	7	7	0	3	12.7	< 0.01	Clumped
Melicope lunu-ankenda (Gaertn.) T.G. Hartley	Rutaceae	Tree	0	1	2	0	0.75	3.7	0.30	Random
Excoecaria oppositifolia var. *crenulata* (Wight) Chakrab. & M. Gangop.	Euphorbiaceae	Tree	0	0	0	1	0.25	3	0.39	Random
Hedyotis swertioides Hook.f.	Rubiaceae	Shrub	0	1	0	0	0.25	3	0.39	Random
Ichnocarpus frutescens (L.) W.T.Aiton	Apocynaceae	Liana	0	0	1	0	0.25	3	0.39	Random
Ilex wightiana Wall. ex Wight	Aquifoliaceae	Tree	0	4	2	1	2.5	5.2	0.16	Random
Lasianthus venulosus (Wight & Arn.) Wight	Rubiaceae	Shrub	0	0	0	2	1.5	18	< 0.0005	Clumped

Contd...

Appendix Table 1. Continued.

Sapling names	Family	Life-form	TP (%)	UTPI (%)	UTP2 (%)	SP (%)	Mean	χ2	*P*-value	Spatial pattern
Ligustrum perrottetii A. DC.	Oleaceae	Tree	5	0	1	9	9.5	72.6	< 0.0001	Clumped
Litsea floribunda Gamble.	Lauraceae	Tree	0	0	2	0	0.5	6	0.11	Random
Litsea glabrata Hook.f.	Lauraceae	Tree	2	6	2	26	26.75	275.13	< 0.0001	Clumped
Litsea stocksii Hook.f.	Lauraceae	Tree	0	0	0	0	0.25	3	0.39	Random
Maesa indica (Roxb.) A. DC.	Primulaceae	Tree	10	12	10	0	7.25	7.55	< 0.06	Clumped
Mahonia napaulensis DC.	Berberidaceae	Tree	0	1	0	0	0.25	3	0.39	Random
Meliosma simplicifolia (Roxb.) Walp.	Sabiaceae	Tree	0	0	0	3	2.75	33	< 0.0001	Clumped
Magnolia nilagirica (Zenker) Figlar	Magnoliaceae	Tree	0	1	1	0	0.5	2	0.58	Random
Phoebe wightii Meisn.	Lauraceae	Tree	0	0	0	1	0.25	3	0.39	Random
Psychotria bisulcata Wight & Arn.	Rubiaceae	Shrub	0	0	0	2	1.75	21	< 0.0001	Clumped
Psychotria nervosa Sw.	Rubiaceae	Shrub	0	0	0	3	2.75	33	< 0.0001	Clumped
Rhamnus wightii Wight & Arn.	Rhamnaceae	Liana	4	7	15	1	6.5	15.61	< 0.002	Clumped
Rhododendron nilagiricum Zenker.	Ericaceae	Tree	0	1	0	0	0.25	3	0.39	Random
Rhodomyrtus tomentosa (Aiton) Hassk.	Myrtaceae	Tree	0	0	4	0	1	12	< 0.008	Clumped
Symplocos cochinchinensis (Lour.) S. Moore	Symplocaceae	Tree	2	0	1	6	6.5	56.2	< 0.0001	Clumped
Symplocos foliosa Wight.	Symplocaceae	Tree	0	0	0	1	0.5	6	0.11	Random
Syzygium densiflorum Wall. ex Wight & Arn.	Myrtaceae	Tree	5	1	5	0	3	5.3	0.15	Random
Tarenna asiatica (L.) Kuntze ex K. Schum.	Rubiaceae	Tree	0	0	1	0	0.25	3	0.39	Random
Toddalia asiatica (L.) Lam.	Rutaceae	Liana	0	0	1	0	0.25	3	0.39	Random