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Floristic composition, diversity and stand structure of a mature abandoned teak (*Tectona grandis* L.f.) plantation in Central Kerala, India

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Abstract

The study examined the tree species composition, diversity and stand structure of a mature teak (*Tectona grandis* L.f.) plantation raised in 1963 and later left unmanaged at Elanad, Machad Forest Range, Thrissur, Kerala. Fifty quadrats of 10 m × 10 m (0.5 ha) were laid out and all trees ≥ 10 cm diameter at breast height were enumerated. Twenty-six species belonging to 22 genera and 15 families were recorded. The stand was dominated by *Tectona grandis* (IVI 105.64), followed by *Xylia xylocarpa* (60.23) and *Terminalia paniculata* (37.86); these three species held 71.4 per cent of the stems and 73.4 per cent of the basal area. Lamiaceae had the highest family importance value (87.06), followed by Fabaceae (76.22) and Combretaceae (45.95). The Shannon-Wiener index (H') was 2.06, Simpson's dominance index 0.21, Margalef's richness index 4.36 and equitability 0.63. Stand density was 616 stems ha⁻¹ and basal area 35.94 m² ha⁻¹. The girth class distribution was reverse J-shaped, with 36.4 per cent of the stems in the 30-60 cm class, where associate species formed 73.2 per cent of the stems. Twenty-two species were contagiously distributed and four, including teak, were random. Associate species now contribute 62.7 per cent of the stems and 58.5 per cent of the basal area, showing that secondary succession towards moist deciduous forest is in progress, although evergreen and shade-tolerant species remain scarce.

Keywords: Phytosociology, importance value index, species diversity, secondary succession

1. Introduction

Nearly one billion hectares of tropical forest land are degraded and in need of restoration (ITTO 2020) [27]. Forest degradation alone releases about 2.1 billion tonnes of CO₂ annually (Pearson *et al.*, 2017) [48]. The United Nations Decade on Ecosystem Restoration (2021-2030), the Bonn Challenge and REDD+ seek to restore such landscapes at scale (Chazdon *et al.*, 2016) [7]. Degraded natural forests remain the main focus of restoration programmes. Unproductive and abandoned forest plantations are a substantial but under-recognised opportunity, particularly in the Western Ghats of Kerala, where monoculture stands of teak (*Tectona grandis* L.f.) have fragmented natural forest cover (Vijayan *et al.*, 2021) [67]. Teak planting in Kerala expanded after the National Forest Policy of 1952, which converted large areas of natural forest to meet industrial timber demand. The Wildlife (Protection) Act of 1972, the National Forest Policy of 1988 and the subsequent restrictions on felling halted further conversion. Many existing stands, especially those in protected and ecologically sensitive areas, were subsequently left without silvicultural management (Harikrishnan *et al.*, 2012) [23]. Teak plantations meet less than 10 per cent of Kerala's wood demand (Krishnankutty *et al.*, 2008) [30]. About 45,000 ha of the State's roughly 90,000 ha of tea plantations, those that are degraded, failed, of poor site quality or ecologically sensitive, are now earmarked for phased eco-restoration to natural forest (GOK, 2021) [19].

Whether such plantations recover native forest composition through natural succession alone, or need active intervention, is still debated. Plantation monocultures have been described as species-poor green deserts (Bremer and Farley, 2010) [5], and teak stands in Costa Rica impeded native species establishment relative to abandoned pasture (Healey and Gara, 2003) [25]. In contrast, abandoned teak plantations of the southern Western Ghats supported native woody regeneration

comparable to nearby secondary forest (Harikrishnan *et al* 2012)^[23], and an abandoned mixed plantation at Kannavam, northern Kerala, approached the diversity of typical moist deciduous forest (Abhilash *et al.*, 2013)^[11]. In central India, the larger size classes of teak plantations remained dominated by teak (Saha, 2001)^[53]. These contrasting results show that succession under teak is site-specific.

Site-specific evidence on the floristic composition and successional status of abandoned teak plantations is still limited for Kerala, despite the policy commitment to restore them. The present study therefore quantified the tree species composition, diversity, dominance and size class structure of a mature abandoned teak plantation in central Kerala, to infer its successional trajectory and to support site-specific eco-restoration planning.

2. Materials and Methods

Study area: The study was conducted at Elanad Station, Machad Forest Range, Thrissur Forest Division, Kerala, in the Western Ghats region of peninsular India (10°35'-10°43' N, 76°14'-76°27' E; altitude 30-550 m) (Fig. 1). The climate is warm and humid, with maximum temperatures of 34-38°C during March-May, relative humidity of 60-90 per cent and a mean annual rainfall of about 1500 mm (Menon and Nair, 2002)^[36]. The soils are sandy loam to reddish loam over gneissic parent material with laterite outcrops. The forest types of the division are wet evergreen and moist deciduous, with an intermediate semi-evergreen type in parts. A teak plantation raised in 1963 at Elanadu, Thrissur left unmanaged after silvicultural operations ceased, was selected after a reconnaissance survey. The stand was about 60 years old at sampling.

Vegetation sampling: Field data were collected between January 2023 and December 2024. Fifty quadrats of 10 m × 10 m were laid out in the plantation, giving a sampled area of 0.5 ha (Mueller-Dombois and Ellenberg, 1974)^[38]. All trees with DBH ≥ 10 cm were identified and enumerated. Girth at breast height (1.37 m) was measured with a tape and converted to diameter, and tree height was recorded with a laser hypsometer (Forestry Pro II, Nikon). Species were identified with standard floras and the help of taxonomists at the Kerala Forest Research Institute, Peechi.

Floristic structure and diversity: Abundance, density, frequency, basal area and their relative values were calculated following Curtis and McIntosh (1950)^[11]. The importance value index (IVI) was derived as the sum of relative density, relative frequency and relative basal area. The family importance value (FIV) was calculated as the sum of relative density, relative basal area and relative diversity of each family (Mori *et al.*, 1983)^[37]. The distribution pattern of each species was inferred from the abundance to frequency ratio: < 0.025 regular, 0.025-0.05 random and > 0.05 contagious (Curtis and Cottam, 1956)^[10]. Stems were grouped into six girth classes (30-60, 60-90, 90-120, 120-150, 150-180 and > 180 cm GBH) to examine population structure. The Shannon-Wiener index (H'), Simpson's dominance index (D), Margalef's and Menhinick's richness indices, equitability (J) and Hill's diversity numbers were computed following Magurran (1988)^[34], using PAST and Biodiversity Pro.

3. Results and Discussion

Floristic composition: The plantation held 308 trees of 26 species, 22 genera and 14 families in the 0.5 ha sampled (Table 1). Fabaceae was the most species-rich family (7 species), followed by Combretaceae (4) and Lamiaceae, Phyllanthaceae and Malvaceae (2 each); the other nine families had one species each. Legume dominance of the tree flora is a general feature of

tropical forests (Gentry, 1988)^[17] and was recorded in the deciduous forests of Suruli Falls (Naveenkumar and Sundarapandian, 2018)^[43], Tiruvannamalai (Gandhi and Sundarapandian, 2014)^[15] and under teak plantations in Thailand (Kaewkrom *et al.*, 2005)^[29]. Nine species were represented by a single tree and seven by two trees, so 16 of the 26 species (61.5 per cent) were rare in the stand. Species number per quadrat ranged from one to six, with a mean of 3.36. The richness is higher than the 19 species of the abandoned plantation at Kannavam (Abhilash *et al.*, 2013)^[11] and matches the 24-26 species ha⁻¹ estimated for the natural moist deciduous forests of Thrissur Forest Division, of which the study site is a part (Valappil and Swarupanandan., 1996)^[63]. It is close to the 30-35 species ha⁻¹ of Puerto Rican dry forest (Murphy and Lugo, 1986)^[40], but below the 39 species ha⁻¹ of Suruli Falls (Naveenkumar and Sundarapandian, 2018)^[43], the 58 species of Shendurney (Bilyaminu *et al.*, 2021)^[4], the 87 species of tropical dry forest in Costa Rica (Hubbell, 1979)^[26] and the 93-129 species reported from deciduous forests of western India and the Eastern Ghats (Kumar *et al* 2010, Naidu and Kumar, 2016)^[31, 42]. Plot size and the 10 cm DBH threshold affect such comparisons (Sagar *et al.*, 2003)^[52].

Stand density and basal area: Stand density was 616 stems ha⁻¹ and basal area 35.94 m² ha⁻¹. The density is lower than the 876.97 stems ha⁻¹ of Shendurney (Bilyaminu *et al.*, 2021)^[4] but higher than the 502 stems ha⁻¹ of the Suruli Falls moist deciduous forest (Naveenkumar and Sundarapandian, 2018)^[43], and lies within the 276-905 stems ha⁻¹ range reported for the forests of the Western Ghats (Ghate *et al.*, 1998)^[18]. The basal area exceeds the 14.7 m² ha⁻¹ given for Indian moist deciduous forests as a whole (Seth and Kaul, 1978)^[57], the 16.52 m² ha⁻¹ of Suruli Falls, the 26.88 m² ha⁻¹ of Shendurney and, most notably, the mean of 12.83 m² ha⁻¹ of the fire- and grazing-affected natural moist deciduous forests of Thrissur Division (Valappil and Swarupanandan, 1996)^[63]. It falls within the 20-75 m² ha⁻¹ range of moist tropical forests (Murphy and Lugo, 1986)^[40] and the 21.50-47.30 m² ha⁻¹ reported for dry deciduous forests of Chhattisgarh (Lal *et al.*, 2015)^[32]. Teak alone contributed 14.92 m² ha⁻¹, but the 25 associate species together held 21.02 m² ha⁻¹, itself more than the natural forest mean of the Division. Differences in basal area between stands are governed by species composition, tree age and the degree of disturbance (Sundarapandian and Swamy, 2000)^[60]. The high value here reflects both the retained 60-year-old teak crop and six decades of undisturbed growth of the associates, in a stand spared the recurrent fire and grazing that depress the natural forests of the Division (Swarupanandan and Sasidharan, 1992)^[62]. The largest trees were *Melia dubia* (321 cm GBH), *Terminalia bellirica* (249 cm) and *Tectona grandis* (198 cm).

Species importance: *Tectona grandis* had the highest IVI (105.64), with 37.34 per cent of the stems, 41.52 per cent of the basal area and a frequency of 90 per cent; only five quadrats lacked teak. It was followed by *Xylia xylocarpa* (60.23), *Terminalia paniculata* (37.86), *Cleistanthus collinus* (17.40), *Miliusa tomentosa* (13.35), *Macaranga peltata* (9.19) and *Bombax ceiba* (8.11). The first three species accounted for an IVI of 203.73 out of 300, and 17 species had an IVI below five. Mono-dominant stands occur side by side with mixed forest in the Asian and American tropics and usually follow a major disturbance sustained over a long period (Hart *et al.*, 1989)^[24]; a planted monoculture is an extreme case. Comparable dominance occurs in natural deciduous forests of the region, where *Pterocarpus marsupium* held one-third of the IVI (113) at Suruli Falls

(Naveenkumar and Sundarapandian, 2018) ^[43], and in the abandoned plantation at Kannavam, where teak had an IVI of 110.59 (Abhilash *et al.*, 2013) ^[1]. What distinguishes the Machad stand is the identity of the sub-dominants. *Xylia xylocarpa* had the highest basal area (4.06 m² ha⁻¹), density and relative importance value of all species in the natural moist deciduous forests of Thrissur Division, with *Terminalia paniculata*, *Grewia tiliifolia* and *Melia dubia* among the other leading upper-storey species (Valappil and Swarupanandan, 1996) ^[63]. *Terminalia paniculata* was also the leading species at Shendurney (Bilyaminu *et al.*, 2021) ^[4], in the moist deciduous forest of Kodayar (Sundarapandian and Swamy, 2000) ^[60] and in Uttara Kannada (Murthy *et al.*, 2016) ^[41]. At Kannavam, in contrast, the second rank went to the evergreen understorey species *Aporosa lindleyana* (Abhilash *et al.*, 2013) ^[1]. The species hierarchy below teak at Machad thus reproduces that of the surrounding natural forest. *Xylia xylocarpa* regenerates well even in disturbed sites because of its abundant seed, fire resistance, coppicing and root suckering (Valappil and Swarupanandan, 1996) ^[63], and it was among the climax species that established early under teak plantations in Thailand (Kaewkrom *et al.*, 2005) ^[29]. The presence of *Macaranga peltata*, a light-demanding pioneer, points to canopy gaps within the ageing teak crop.

Family importance: Lamiaceae had the highest FIV (87.06), almost entirely because of teak, followed by Fabaceae (76.22), Combretaceae (45.95), Phyllanthaceae (17.64), Malvaceae (15.02) and Annonaceae (10.64). Six families had an FIV above ten (Table 2). Apart from Lamiaceae, the ranking resembles that of natural deciduous forest. Combretaceae is the most important family in the moist deciduous forest of Kodayar (Sundarapandian and Swamy, 2000) ^[60] and the second at Shendurney (Bilyaminu *et al.*, 2021) ^[4]; Combretaceae and Euphorbiaceae lead in the deciduous forests of the Eastern Ghats (Naidu and Kumar, 2016; Pragasan and Parthasarathy, 2010) ^[42, 50], and Fabaceae contributed 32 per cent and Combretaceae 17 per cent of the stems at Suruli Falls (Naveenkumar and Sundarapandian, 2018) ^[43]. Euphorbiaceae, the most diverse family in many tropical deciduous forests (Panda *et al.*, 2013) ^[45] and the leading family at Shendurney, was represented at Machad by *Macaranga peltata* alone (FIV 8.87).

Species diversity: The Shannon-Wiener index was 2.06, Simpson's dominance index 0.21 (1-D = 0.79), Margalef's index 4.36, Menhinick's index 1.48 and equitability 0.63 (Table 3). The H' value lies within the range of 0.83-4.0 reported for Indian forests (Singh *et al.* 1984) ^[58] and is almost identical to the 2.13 of the Kannavam plantation (Abhilash *et al.*, 2013) ^[1]. It is close to the values of the natural moist deciduous forests of Kerala: 1.9 at Parambikulam (Sankar and Sanalkumar, 1997) ^[56], 1.89-2.37 at Chimmony (Suraj, 1997) ^[61] and 2.28 at Peppara (Varghese, 1997) ^[64]. It is also close to the 2.38 of Suruli Falls, where dominance (0.20) and evenness (0.28, e^H/S) were almost the same as at Machad (0.21 and 0.30) (Naveenkumar and Sundarapandian 2018) ^[43], but well below the 3.22 of Shendurney (Bilyaminu *et al.* 2021) ^[4], the 3.38 of Malyagiri (Sahu *et al.* 2012) ^[55] and the 3.66-4.86 reported from other deciduous forests of India (Reddy *et al.* 2011) ^[51]. Margalef's index (4.36) exceeded the 3.46 of Kannavam and lay within the 2.38-4.18 of Peppara (Varghese 1997) ^[64], but was far below the 7.92 of Shendurney and the 8.82-10.17 of the New Amarambalam and Goodricol forests (Jayakumar 2003) ^[28]; this index is sensitive to sample size (Magurran 2005) ^[35], and the 0.5 ha sampled here is small. Hill's N1 of 7.84 means that the 26 species are equivalent to only about

eight equally common species. As at Suruli Falls, where the single-species dominance of *Pterocarpus marsupium* lowered H' below that of the poorer dry deciduous forest (Naveenkumar and Sundarapandian 2018) ^[43], low evenness caused by the concentration of stems in three species, rather than low species number, is what limits diversity in this stand. The comparison with Thailand is instructive: 12-year-old pure teak plantations there had an understorey H' of only 1.27, against 2.08-2.83 under mixed-species plantations (Kaewkrom *et al.* 2005) ^[29], and tree diversity under plantations on degraded land in central India was likewise low in the early decades (Verma *et al.* 1999) ^[65]. The Machad stand, six decades after planting and without any admixture, has reached the diversity of those mixed stands and of the regional moist deciduous forest.

Girth class distribution: Stem density declined steadily with girth, from 224 stems ha⁻¹ (36.4 per cent) in the 30-60 cm class to 6 stems ha⁻¹ (1.0 per cent) each in the 150-180 cm and > 180 cm classes, giving a reverse J-shaped curve (Table 4). Species number fell in the same way, from 16 species in each of the two lowest classes to three in each of the two highest. Basal area peaked in the 90-120 cm class (11.95 m² ha⁻¹, 33.2 per cent). The diameter distribution of a stand records the disturbance it has undergone (Denslow, 1995) ^[12] and reveals trends in regeneration (Poorter *et al.*, 1996) ^[49]. A reverse J-shaped decline in stem number with size is the norm for the deciduous forests of the region: it was recorded in the moist deciduous forests of Thrissur Division (Valappil and Swarupanandan, 1996) ^[63], at Shendurney, where 43.1 per cent of the stems were in the lowest class (Bilyaminu *et al.*, 2021) ^[4], at Suruli Falls (Naveenkumar and Sundarapandian, 2018) ^[43], in the moist deciduous forests of the Eastern Ghats of Odisha (Sahoo *et al.*, 2020) ^[54] and in the evergreen forests of Kalakad-Mundanthurai (Ganesh *et al.*, 1996) ^[16]. Unlike stands where the largest classes are depleted by timber extraction (Hadi *et al.*, 2009) ^[21], the Machad stand retains emergent trees above 180 cm GBH.

The stand-level curve hides contrasting population structures (Table 5). Teak stems were spread almost evenly over the 30-60, 60-90 and 90-120 cm classes (26.1, 32.2 and 28.7 per cent), which reflects the even-aged origin of the planted crop rather than continuous recruitment. The 30 teak stems in the lowest class are more likely to be suppressed planted trees, the smaller individuals that self-thinning eliminates from dense populations (Bazzaz and Harper, 1976) ^[3], than later recruits: teak regeneration at the pole stage was absent in the natural moist deciduous forests of Thrissur Division (Valappil and Swarupanandan, 1996) ^[63], and teak seedlings were sparse even under teak plantations in Thailand, owing to the hard seed coat, competition and shade intolerance (Kaewkrom *et al.*, 2005) ^[29]. *Xylia xylocarpa* was unimodal, with 43.9 per cent of its stems in the 60-90 cm class, suggesting a cohort that established early after management ceased. *Terminalia paniculata* showed a reverse J-shaped structure (48.7, 25.6, 15.4 and 10.3 per cent over the first four classes), which indicates continuous recruitment. *Cleistanthus collinus*, *Miliusa tomentosa* and *Macaranga peltata* had 68.4, 71.4 and 91.7 per cent of their stems in the lowest class and are recent entrants to the tree layer. Associate species formed 73.2 per cent of the stems in the 30-60 cm class, whereas teak still formed 47.1 per cent of the stems of 90 cm GBH and above. Persistent teak dominance of the larger size classes was also noted in central India (Saha, 2001) ^[53]. Species can replace one another in the canopy over long periods when recruitment differs, as *Anogeissus latifolia* has replaced *Pterocarpus marsupium* at Mudumalai since the nineteenth century (Cleghorn 1861, Verma and Jayakumar 2015)

[8, 66]; the recruitment of *Terminalia paniculata* and *Xylia xylocarpa* beneath a non-regenerating teak canopy points to a similar replacement here. *Melia dubia*, represented by two very large trees and no smaller stems, fits the pattern described for the natural forest, where the species fruits abundantly but regenerates poorly (Valappil and Swarupanandan, 1996) [63]. Vertically, 26.6 per cent of the stems were below 10 m in height, 54.9 per cent were between 10 and 20 m and 18.5 per cent were above 20 m; *Melia dubia*, *Terminalia bellirica* and *Xylia xylocarpa* reached 31 m, above the tallest teak (28 m). These emergents belong to the upper stratum (25-35 m) of the natural forest (Valappil and Swarupanandan, 1996) [63], and the two-storeyed profile of the stand, a teak-dominated main canopy with taller native emergents, is a structural signature of the transition from plantation to forest.

Distribution pattern: Twenty-two species were contagiously distributed and four were random: *Tectona grandis* (AB/F 0.028), *Terminalia paniculata* (0.029), *Xylia xylocarpa* (0.042) and *Cleistanthus collinus* (0.048). No species was regular. Contagious distribution is the common pattern in natural vegetation (Odum, 1971) [44] and predominates in the deciduous forests of peninsular India: 57 of 58 species at Shendurney (Bilyaminu *et al.*, 2021) [4], 52 of 57 species at Malyagiri in the Eastern Ghats (Sahu *et al.*, 2012) [55], 47 of 52 species at Suruli Falls (Naveenkumar and Sundarapandian, 2018) [43] and most species in the dry forests of East Godavari (Srinivas and Sundarapandian, 2018) [59]. Random distribution is associated with species exposed to large, recurrent disturbances (Armesto *et al.*, 1986) [21]; here the near-regular value of teak reflects the original planting espacement, and the random distribution of the three leading associates shows that they have spread through the whole stand rather than remaining clumped around gaps or seed trees. The ratio is sensitive to low counts, and the high values of the 16 species with one or two trees should be read with caution.

Successional status and management implications: Sixty years after planting, the 25 associate species contributed 62.7 per cent of the stems and 58.5 per cent of the basal area (21.02 m² ha⁻¹). The associates, *Xylia xylocarpa*, *Terminalia spp.*, *Grewia tiliifolia*, *Dalbergia spp.*, *Pterocarpus marsupium*, *Lannea coromandelica*, *Schleichera oleosa* and *Bombax ceiba*, are the upper-storey species of the natural moist deciduous forests of the Division (Valappil and Swarupanandan, 1996) [63], so the stand is developing towards the regional forest type rather than an alien assemblage. This confirms for a Kerala teak stand the role of plantations as foster ecosystems that catalyse native forest recovery on degraded land (Parrotta, 1993; Lugo *et al.*, 1993) [33, 46], a role documented for plantations in Costa Rica (Guariguata *et al.*, 1995; Carnevale and Montagnini, 2002) [6, 20], Uganda (Fimbel and Fimbel, 1996) [13] and the southern Western Ghats (Harikrishnan *et al.*, 2012) [23]. Several of the associates, *Xylia*, *Pterocarpus*, *Lannea*, *Schleichera* and *Terminalia*, are the same genera that established as climax species in the early stages of succession under teak in Thailand (Kaewkrom *et al.*, 2005) [29], in keeping with the tolerance model of succession in which late-successional species arrive alongside pioneers rather than after them (Connell and Slatyer, 1977) [9]. Recovery is nevertheless incomplete. Overstorey composition governs which native species colonise a plantation (Parrotta, 1995) [47], and a single-species teak canopy is a selective filter. The evergreen understorey species *Olea dioica* and *Aporosa cardiosperma*, which ranked among the four most important species both at Shendurney and at Kannavam, were represented here by only 4 stems ha⁻¹ each, and the middle stratum, the most species-rich

layer of the natural forest with 39 species (Valappil and Swarupanandan, 1996) [63], is poorly filled. Valuable timber species such as *Dalbergia latifolia* and *Pterocarpus marsupium* occurred at 2 stems ha⁻¹ each. Passive recovery has therefore rebuilt the deciduous canopy matrix but not the full species complement. Upper-storey species of these forests regenerate best at about 10 per cent canopy gap (Valappil and Swarupanandan, 1996) [63], and tropical canopy trees generally need an optimum, not maximum, canopy opening (Halle *et al.*, 1978) [22], which argues for gradual, gap-creating reduction of teak rather than clear removal of the canopy. Enrichment planting of the scarce evergreen and high-value native species, recommended for species with inadequate regeneration in the moist forests of Kerala (Muraleedharan *et al.*, 2001) [39] and for accelerating succession under teak plantations (Kaewkrom *et al.*, 2005) [29], would complete the process. Protection from fire, grazing and browsing, the main constraints on natural regeneration in tropical moist forests (Fox, 1976) [14] and in the natural forests of the Division (Swarupanandan and Sasidharan, 1992) [62], must continue. The study covered only trees of 10 cm DBH and above; the regeneration layer needs separate assessment.

Table 1: Phytosociological parameters of tree species (DBH ≥ 10 cm) in the mature abandoned teak plantation at Machad, Thrissur, Kerala

Species	Family	AB	AB/F	Ds	RD	PF	RF	BA	RBA	IVI
<i>Tectona grandis</i>	Lamiaceae	2.5 6	0.02 8	23 0	37.34	90	26.79	14.9 2	41.52	105.6 4
<i>Xylia xylocarpa</i>	Fabaceae	2.3 6	0.04 2	13 2	21.43	56	16.67	7.96	22.13	60.23
<i>Terminalia paniculata</i>	Combretaceae	1.5 0	0.02 9	78	12.66	52	15.48	3.50	9.73	37.86
<i>Cleistanthus collinus</i>	Phyllanthaceae	1.3 6	0.04 8	38	6.17	28	8.33	1.04	2.89	17.40
<i>Miliusa tomentosa</i>	Annonaceae	1.2 7	0.05 8	28	4.55	22	6.55	0.81	2.25	13.35
<i>Macaranga peltata</i>	Euphorbiaceae	1.7 1	0.12 2	24	3.90	14	4.17	0.40	1.12	9.19
<i>Bombax ceiba</i>	Malvaceae	1.4 0	0.14 0	14	2.27	10	2.98	1.03	2.87	8.11
<i>Melia dubia</i>	Meliaceae	1.0 0	0.25 0	4	0.65	4	1.19	1.70	4.72	6.56
<i>Terminalia elliptica</i>	Combretaceae	1.2 5	0.15 6	10	1.62	8	2.38	0.71	1.96	5.97
<i>Holarrhena pubescens</i>	Apocynaceae	1.6 7	0.27 8	10	1.62	6	1.79	0.12	0.33	3.74
<i>Terminalia bellirica</i>	Combretaceae	1.0 0	0.50 0	2	0.32	2	0.60	0.99	2.75	3.67
<i>Grewia tiliifolia</i>	Malvaceae	1.0 0	0.25 0	4	0.65	4	1.19	0.55	1.54	3.38
<i>Albizia odoratissima</i>	Fabaceae	1.0 0	0.25 0	4	0.65	4	1.19	0.41	1.13	2.97
<i>Careya arborea</i>	Lecythidaceae	1.5 0	0.37 5	6	0.97	4	1.19	0.20	0.55	2.71
<i>Albizia lebeck</i>	Fabaceae	1.0 0	0.25 0	4	0.65	4	1.19	0.14	0.39	2.23
<i>Cassia fistula</i>	Fabaceae	1.0 0	0.25 0	4	0.65	4	1.19	0.12	0.34	2.18
<i>Olea dioica</i>	Oleaceae	1.0 0	0.25 0	4	0.65	4	1.19	0.10	0.29	2.13
<i>Aporosa cardiosperma</i>	Phyllanthaceae	1.0 0	0.25 0	4	0.65	4	1.19	0.08	0.24	2.08
<i>Lannea coromandelica</i>	Anacardiaceae	1.0 0	0.50 0	2	0.32	2	0.60	0.37	1.04	1.96
<i>Caryota</i>	Arecaceae	1.0	0.50	2	0.32	2	0.60	0.33	0.91	1.83

<i>urens</i>		0	0							
<i>Dalbergia latifolia</i>	Fabaceae	1.0	0.50	2	0.32	2	0.60	0.16	0.43	1.35
<i>Dalbergia lanceolaria</i>	Fabaceae	1.0	0.50	2	0.32	2	0.60	0.10	0.28	1.20
<i>Pterocarpus marsupium</i>	Fabaceae	1.0	0.50	2	0.32	2	0.60	0.09	0.25	1.17
<i>Gmelina arborea</i>	Lamiaceae	1.0	0.50	2	0.32	2	0.60	0.07	0.19	1.11
<i>Schleichera oleosa</i>	Sapindaceae	1.0	0.50	2	0.32	2	0.60	0.03	0.09	1.01
<i>Ficus exasperata</i>	Moraceae	1.0	0.50	2	0.32	2	0.60	0.03	0.09	1.01
Total				61	100.0	33	100.0	35.9	100.0	300.0
				6	0	6	0	4	0	0

AB: abundance; AB/F: abundance to frequency ratio; Ds: density (stems ha^{-1}); RD: relative density (%); PF: per cent frequency; RF: relative frequency (%); BA: basal area ($\text{m}^2 \text{ha}^{-1}$); RBA: relative basal area (%); IVI: importance value index

Table 2: Family importance value (FIV) of the mature abandoned teak plantation

Family	Species (No.)	Density (stems ha^{-1})	Basal area ($\text{m}^2 \text{ha}^{-1}$)	FIV
Lamiaceae	2	232	14.99	87.06
Fabaceae	7	150	8.97	76.22
Combretaceae	3	90	5.19	40.58
Phyllanthaceae	2	42	1.12	17.64
Malvaceae	2	18	1.58	15.02
Annonaceae	1	28	0.81	10.64
Meliaceae	1	4	1.70	9.21
Euphorbiaceae	1	24	0.40	8.87
Apocynaceae	1	10	0.12	5.80
Lecythidaceae	1	6	0.20	5.37
Anacardiaceae	1	2	0.37	5.21
Arecaceae	1	2	0.33	5.08
Oleaceae	1	4	0.10	4.79
Sapindaceae	1	2	0.03	4.26
Moraceae	1	2	0.03	4.26

Table 3: Community indices of the mature abandoned teak plantation

Community index	Value
Species richness (S)	26
Individuals sampled (N)	308
Shannon-Wiener index (H')	2.06
Simpson's dominance index (D)	0.21
Simpson's diversity index (1-D)	0.79
Equitability (J)	0.63
Margalef's richness index	4.36
Menhinick's richness index	1.48
Hill's number N1	7.84
Hill's number N2	4.76

Table 4: Girth class distribution of stems, species and basal area

Girth class (cm GBH)	Density (stems ha^{-1})	Stems (%)	Species (No.)	Basal area ($\text{m}^2 \text{ha}^{-1}$)	Basal area (%)
30-60	224	36.4	16	3.54	9.9
60-90	188	30.5	16	8.44	23.5
90-120	140	22.7	9	11.95	33.2
120-150	52	8.4	7	7.58	21.1
150-180	6	1.0	3	1.18	3.3
>180	6	1.0	3	3.25	9.0
Total	616	100.0	26	35.94	100.0

Table 5: Number of stems of the major species in each girth class (0.5 ha sample)

Species	30-60	60-90	90-120	120-150	150-180	>180	Total
<i>Tectona grandis</i>	30	37	33	13	1	1	115
<i>Xylia xylocarpa</i>	13	29	19	5	0	0	66
<i>Terminalia paniculata</i>	19	10	6	4	0	0	39
<i>Cleistanthus collinus</i>	13	3	3	0	0	0	19
<i>Miliusa tomentosa</i>	10	2	1	1	0	0	14
<i>Macaranga peltata</i>	11	0	1	0	0	0	12
Other species (20)	16	13	7	3	2	2	43
Total	112	94	70	26	3	3	308

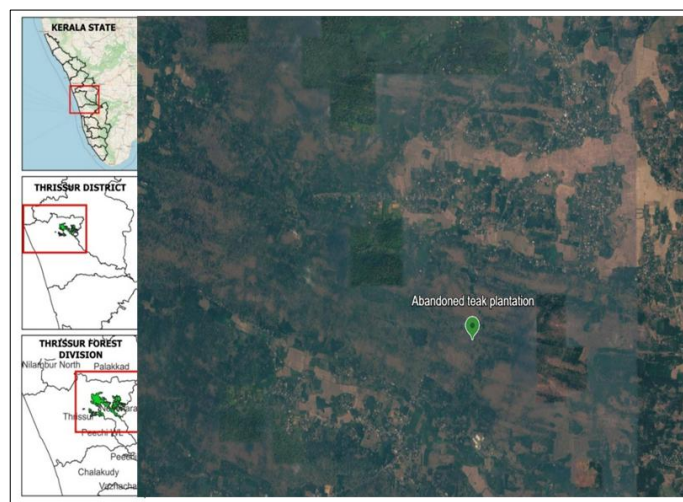


Fig 1: Map of the study area at Machad, Thrissur

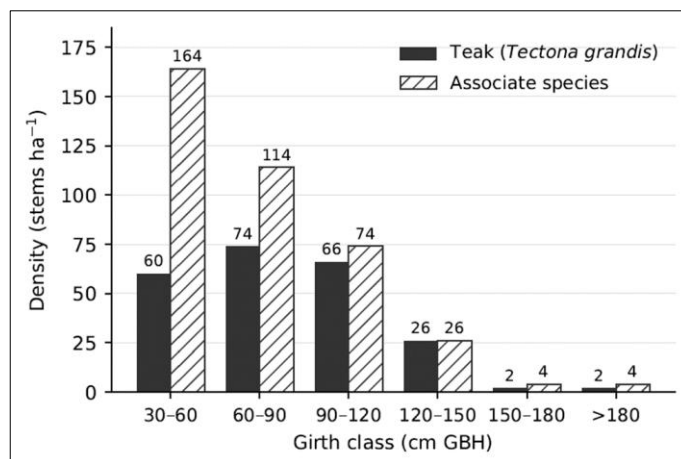


Fig 2: Girth class distribution of teak and associate species in the mature abandoned teak plantation at Machad, Thrissur

4. Conclusion

The 60-year-old abandoned teak plantation at Machad supports 26 tree species at $616 \text{ stems ha}^{-1}$ and $35.94 \text{ m}^2 \text{ha}^{-1}$, with a Shannon-Wiener index of 2.06. Teak remains the single most important species (IVI 105.64) and still dominates the larger girth classes, but associate species of the regional moist deciduous forest, led by *Xylia xylocarpa* and *Terminalia paniculata*, now hold most of the stems and basal area and dominate the lowest girth class. Secondary succession is therefore in progress. The scarcity of evergreen and shade-tolerant species and of valuable native timber species shows that natural recovery alone has not restored the full composition. Eco-restoration of such stands should combine gradual reduction of the teak canopy with enrichment planting of the missing native species.

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