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Two-decadal changes in forest structure and tree diversity in a tropical dry evergreen forest on the Coromandel Coast of India

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Abstract: The establishment and periodic re-inventory of permanent plots are important for studying the long-term changes in forest diversity and dynamics. We re-censused twice a 1-ha permanent plot established in 1992, in a tropical dry evergreen forest at Puthupet on the Coromandel Coast of peninsular India, at an interval of 10 years. The plot was subdivided into one-hundred 10 m x 10 m quadrats for systematic enumeration of all trees ≥10 cm girth at breast height (1.3 m from the ground level). In 2012 census we found 24 species from 21 genera and 17 families and these results were compared with the initial (1992) and decadal (2002) inventories. Overall in twenty years, one species was added and the number of genera and families remained unchanged but there was a heavy reduction in stand basal area (by 33 %) and density (by 57 %), indicating heavy anthropogenic activities at the study site. Such data generated at long-term interval could be useful to understand the forest changes, and for conservation and management of this and similar tropical forests.

Resumen: El establecimiento y la realización de inventarios periódicos en parcelas permanentes son importantes para el estudio de los cambios a largo plazo en la diversidad y la dinámica del bosque. Nosotros repetimos dos veces, a intervalos de 10 años, el censo de una parcela permanente de 1 ha establecida en 1992, en un bosque tropical seco perennifolio en Puthupet, en la costa de Coromandel de la India peninsular. La parcela fue subdividida en 100 cuadros de 10 m × 10 m para la enumeración sistemática de todos los árboles ≥ 10 cm de perímetro a la altura del pecho (1.3 m a partir del suelo). En el censo de 2012 encontramos 24 especies de 21 géneros y 17 familias y estos resultados fueron comparados con el inventario inicial (1992) y el decadal (2002). En términos generales, en 20 años se añadió una especie y el número de géneros y familias permaneció inalterado, pero hubo reducciones severas en el área basal del rodal (33 %) y la densidad (57 %), lo que indica la presencia de actividades antropogénicas intensas en el sitio de estudio. Este tipo de datos generados en un intervalo de largo plazo podrían ser útiles para entender los cambios en el bosque, y para la conservación y el manejo de este bosque tropical y de otros similares.

Resumo: O estabelecimento e a realização de inventários periódicos em parcelas permanentes são importantes para o estudo das mudanças de longo prazo na diversidade e na dinâmica da floresta. Reinventariámos duas vezes, com um intervalo de 10 anos, uma parcela de 1 ha permanente estabelecida em 1992, numa floresta tropical seca sempreverde em Puthupet na costa de Coromandel na Índia peninsular. A parcela foi subdividida em 100 quadrados de 10 m x 10 m de lado para enumeração sistemática de todas as árvores ≥ 10 cm de perímetro à altura do peito (1,3 m do nível do solo). No inventário de 2012 encontrámos 24 espécies de 21 géneros e 17 famílias e estes resultados foram comparados com os dos inventários inicial (1992) e o da década (2002). Em termos gerais, em vinte anos, uma espécie foi adicionada e o número de géneros e famílias permaneceu inalterado, mas houve uma redução forte na área basal (33 %) e na densidade (57 %), indicando uma severas atividades antropogénicas no local de estudo. Tais

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dados gerados num intervalo longo prazo poderão ser úteis para entender as mudanças a floresta, e para a conservação e gestão desta floresta tropical e de outras florestas tropicais similares.

Key words: Tropical dry evergreen forest, permanent plot, re-census, stand structural change, species and density loss.

Tropical dry forests (TDF) are ecologically, socially and economically highly valued all over the world (Mooney *et al.* 1995) and provide many goods and ecosystem services (Armentaras *et al.* 2009; Li *et al.* 2003; Wang 2003). However, most TDFs are exposed to a range of threats, mainly from human disturbances (Yosi *et al.* 2011). Tropical dry evergreen forest (TDEF) is a tree-dominated, closed canopy forest type, which is restricted to south Asia - on the Coromandel Coast of India, North-eastern Sri Lanka, South-west China and North-eastern Thailand and in Caribbean Islands and south coast of Jamaica (see Parthasarathy *et al.* 2008).

In the Indian sub-continent, the TDEFs occur in patches and are short-statured, largely three-layered, tree-dominated evergreen forests with a sparse, patchy ground flora (Parthasarathy *et al.* 2008). They also harbour a remarkable diversity and density of lianas (Reddy & Parthasarathy 2003). This forest type is distinguishable by a group of characteristic and preferential species (*Manilkara hexandra, Memecylon umbellatum* and *Pterospermum canescens)*, exclusively confined to it (Champion & Seth 1968; Meher-Homji 1974). Long-term monitoring of tree population dynamics and quantitative data generation are essential for forest conservation and management (Lwanga *et al.* 2000; Parthasarathy & Sethi 1997; Proctor *et al.* 1983; Sukumar *et al.* 1998). They are also vital when investigating forest diversity, slow-acting ecological processes and changes (Phillips 1998), and for evaluating the consequence of rare events (Gaines & Denny 1993). We investigated changes in tree diversity and forest structure of a tropical dry evergreen forest on the Coromandel Coast of India over two decades (1992 - 2012) after the establishment of a permanent plot.

The study site, Puthupet (12° 03' N lat. and 79° 52' E long.), is situated 15 km north of Puducherry town. It is a 'sacred grove' or 'temple forest' dedicated to Lord Ayyanar and protected due to the religious belief of the local people. The site is very close to human settlement (~0.2 km) and covers a total of about 17 ha, of which about 5 ha remain under forest cover. The study site is experiencing various anthropogenic activities such as forest encroachment for expansion of temple structures, construction of road, cattle grazing, resource removal (fodder, firewood, medicinal plants, timber, etc.) and the impact of temple visitors by way of cooking inside the forest during festive occasions, vehicle parking and solid waste dumping (polythene, glass bottles, etc.).

The climate is tropical dissymmetric (Meher-Homji 1974) with major rainfall received from the north-east monsoon in October-December. The months of March-May mark dry summer, which is followed by the south-west monsoon season up to September. Dew is an important source of moisture from October to March. Twenty year (1991 - 2011) climate data available from the nearest meteorological station, Puducherry, reveal a mean annual temperature of 29.5 °C and the mean annual rainfall of 1,141 mm. The mean number of rainy days in the annual cycle is 55.5. The mean monthly temperature ranges from 25 °C to 34 °C in a year (Anbarashan & Parthasarathy 2013). The soils are alluvial, sandy loam in texture, overlying on red laterite, beneath which lies the Miocene Cuddalore sandstone formation (Parthasarathy & Sethi 1997; Visalakshi 1995). The vegetation of this site is described as tropical dry evergreen forest (type 7/CI of Champion & Seth 1968).

During the initial inventory in 1992, four 0.5 ha (100 m x 50 m; total 2 ha) plots were inventoried at the Puthupet site (Parthasarathy & Sethi 1997), of which two contiguous 0.5 ha (1 ha) permanent plots (200 m × 50 m) were considered for re-inventory (for logistic reasons) in 2002 (Venkateswaran & Parthasarathy 2005) and all trees ≥ 10 cm girth at breast height (gbh) were re-measured. In the third census (2012), the 1-ha plot (the one re-censused in 2002) was subdivided into one-hundred 10 m x 10 m quadrats for systematic enumeration of all trees ≥ 10 cm gbh, measured at

Table 1. Changes in tree diversity over two decades (1992 - 2012) in a tropical dry evergreen forest at Puthupet on the Coromandel Coast of India.

Variables	Recorded in			Missing
	1992	2002	2012	(in 2002-2012)
Number of species	23	29	24	5
Genera	21	26	21	5
Families	17	21	17	4
Stand density (stems ha^{-1})	1329	1338	591	747
Basal area (m^2 ha^{-1})	37.5	34.5	25.14	9.36

1.3 m height from the ground level. The third re-census results were compared with both the initial (1992) and decadal (2002) inventories to analyse the changes in tree density over two decades (1992 - 2012) at species and stand levels. Tree diversity, in terms of number of species, genera and families was also recorded.

In the third census, in 2012, we recorded 591 trees representing 24 species and 21 genera from 17 families. Overall, in twenty years, one species was added and the number of genera and families remained unchanged (Table 1). As is evident from Table 2, during 1992 - 2002 nine species (*Eugenia bracteata*, *Lannea coromandelica*, *Ixora pavetta*, *Albizia amara*, *Cordia monica*, *Ochna obtusata, Crataeva adansonii*, *Azadirachta indica* and *Flacourtia indica)* were added and three species (*Carmona retusa*, *Morinda pubescens* and *Pongamia pinnata*) were lost. Of the nine species added in 2002, five species (*C. monica, E. bracteata, F. indica, I. pavetta* and *O. obtusata*) are short statured trees which reached 10 cm gbh threshold considered for inventory; and this would partly explain the greater species richness in 2002 census. Between 2002 - 2012 anthropogenic disturbances in the site increased and consequently five species (*Azadirachta indica, Crataeva adansonii, Flacourtia indica, Gmelina asiatica* and *Ochna obtusata*) were lost from the study plot and no species was added (Table 2). Tree density drastically declined by 57 % (from 1329 stems ha^{-1} in 1992 to 591 ha^{-1} in 2012) and tree basal area by 33 % (from 37.5 m^2 ha^{-1} in 1992 to 25.14 m^2 ha^{-1} in 2012). This decline mirrors the rapid forest degradation in our study site that occurred over the two decades due to intense anthropogenic activities. Oliveira *et al.* (2004) and Santos *et al.* (2008) found a sharp reduction in the total number of tree species in disturbed habitats of Brazilian Atlantic forests. Bhat *et al.* (2000) also reported a decrease in tree basal area with increasing disturbance in tropical forests of Uttara Kannada district in Western Ghats, India.

Over the two decades, the stem density of many tree species changed considerably. The change ranged from a decrease of 488 stems ha^{-1} for the predominant species *Memecylon umbellatum* to a gain of 14 stems ha^{-1} for *Pterospermum canescens* (Table 2). Of the total 32 species recorded, 16 species registered loss in stem density, nine species registered a gain and for seven species stem density remained unchanged. Rao *et al.* (1990) and Lalfakawma *et al.* (2009) also reported that species diversity and abundance markedly declined in disturbed stands in North-east India, a sub-tropical broad-leaved hill forest of Meghalaya and a tropical semi-evergreen forest of Lunglei district of Mizoram, respectively.

Tree loss was more during the second decade (2002 - 2012), for example the predominant species of the forest *Memecylon umbellatum* alone lost 508 stems, yet it continued to dominate the forest stand, although the species suffered a 70 % density decline in the second decade. Originally it was a monodominant species occupying ~55 % of the forest stand during 1992 and 2002 censuses, but now reduced with a density of 36 %, thus losing its monodominant status. Stem loss was also notable for the co-dominant species of the study site, *Drypetes sepiaria, Garcinia spicata* and *Canthium dicoccum* (82, 26 and 57 individuals respectively, in 2002 - 2012) but they retained their status as co-dominants. Tree density of another dominant species *Pterospermum canescens* showed an increase by 22 % in 2002 census, but marginally declined by 7 % in 2012 census. Hubbell *et al.* (1999) also demonstrated no change in the presence of dominant species despite large changes in its stem density in a Panamanian tropical forest. Tree density of five species *Albizia amara, Benkara malabarica, Cordia monoica, Ficus amplissima* and *Maytenus emarginata* which was low in the earlier censuses, now further reduced to just one stem each in 2012 census, thus indicating the magnitude of species loss that might lurk in the near future. According to Primack & Hall (1992) and Gilpin & Soule (1986) the species with small population sizes are more prone to local extinction, because the death of a few individuals will result in loss of the species from the forest. In

Table 2. Changes in species density (stems ha^{-1}) of trees (1992 - 2012) arranged in decreasing order of change in density in 2012.

Species	Density			10- yr change		Net Change
	1992	2002	2012	92-02	02-12	
Memecylon umbellatum Burm.f. (Melastomataceae)	703	723	215	20	-508	-488
Pterospermum canescens Roxb. (Sterculiaceae)	101	124	115	23	-9	14
Drypetes sepiaria (Wight & Arn.) Pax & Hoffm. (Euphorbiaceae)	185	158	76	-27	-82	-109
Garcinia spicata (Wight & Arn.) J. D. Hook. (Clusiaceae)	150	93	67	-57	-26	-83
Canthium dicoccum (Gaertn.) Teijsm. & Binn. (Rubiaceae)	82	96	39	14	-57	-43
Diospyros ebenum Koen. (Ebenaceae)	3	15	10	12	-5	7
Chionanthus zeylanica L. (Oleaceae)	27	21	10	-6	-11	-17
Atalantia monophylla (L.) Correa (Rutaceae)	1	10	8	9	-2	7
Lepisanthes tetraphylla (Vahl) Radlk. (Sapindaceae)	23	17	8	-6	-9	-15
Walsura trifolia (A. Juss.) Harms (Meliaceae)	9	11	8	2	-3	-1
Albizia lebbeck (L.) Willd. (Mimosaceae)	7	12	7	5	-5	0
Eugenia bracteata (Willd.) Roxb. ex DC. (Myrtaceae)	0	9	5	9	-4	5
Glycosmis mauritiana (Lam.) Y. Tanaka (Rutaceae)	11	11	4	0	-7	-7
Lannea coromandelica (Houtt.) Merr. (Anacardiaceae)	0	3	3	3	0	3
Syzygium cumini (L.) Skeels (Myrtaceae)	6	2	3	-4	1	-3
Dalbergia paniculata Roxb. (Papilionaceae)	1	2	2	1	0	1
Diospyros ferrea (Willd.) Bakh. var. *buxifolia* (Rottb.) Bakh. (Ebenaceae)	2	3	2	1	-1	0
Ficus benghalensis L. (Moraceae)	4	4	2	0	-2	-2
Ixora pavetta Andr. (Rubiaceae)	0	2	2	2	0	2
Albizia amara (Roxb.) Boivin (Mimosaceae)	0	1	1	1	0	1
Benkara malabarica (Lam.) Tirven. (Rubiaceae)	4	6	1	2	-5	-3
Cordia monoica Roxb. (Boraginaceae)	0	4	1	4	-3	1
Ficus amplissima J.E.Smith (Moraceae)	2	1	1	-1	0	-1
Maytenus emarginata (Willd.) Ding Hou (Celastraceae)	1	1	1	0	0	0
Azadirachta indica A. Juss. (Meliaceae)	0	3	0	3	-3	0
Carmona retusa (Vahl) Masam. (Boraginaceae)	1	0	0	-1	0	-1
Crataeva adansonii (Lour.) DC. (Capparaceae)	0	2	0	2	-2	0
Flacourtia indica (Burm.f.) Merr. (Flacourtiaceae)	0	1	0	1	-1	0
Gmelina asiatica L. (Verbenaceae)	1	2	0	1	-2	-1
Morinda pubescens J. E. Smith (Rubiaceae)	4	0	0	-4	0	-4
Ochna obtusata DC. (Ochnaceae)	0	1	0	1	-1	0
Pongamia pinnata (L.) Pierre (Papilionaceae)	1	0	0	-1	0	-1
Total	1329	1338	591	9	-747	-738

the present study, among the surviving species from 2002 census, 17 species registered density decline; *Sygygium cumini* increased just by one individual and for six species tree density remained unchanged in the span of 2002 - 2012 (Table 2). The net change in tree density of various families over two decades ranged from a loss of 488 stems ha^{-1} of Melastomataceae to a gain of 14 stems of Sterculiaceae. Out of 21 families nine families showed a decline in stem density, while there was a marginal increase in stem density in five families (Fig. 1).

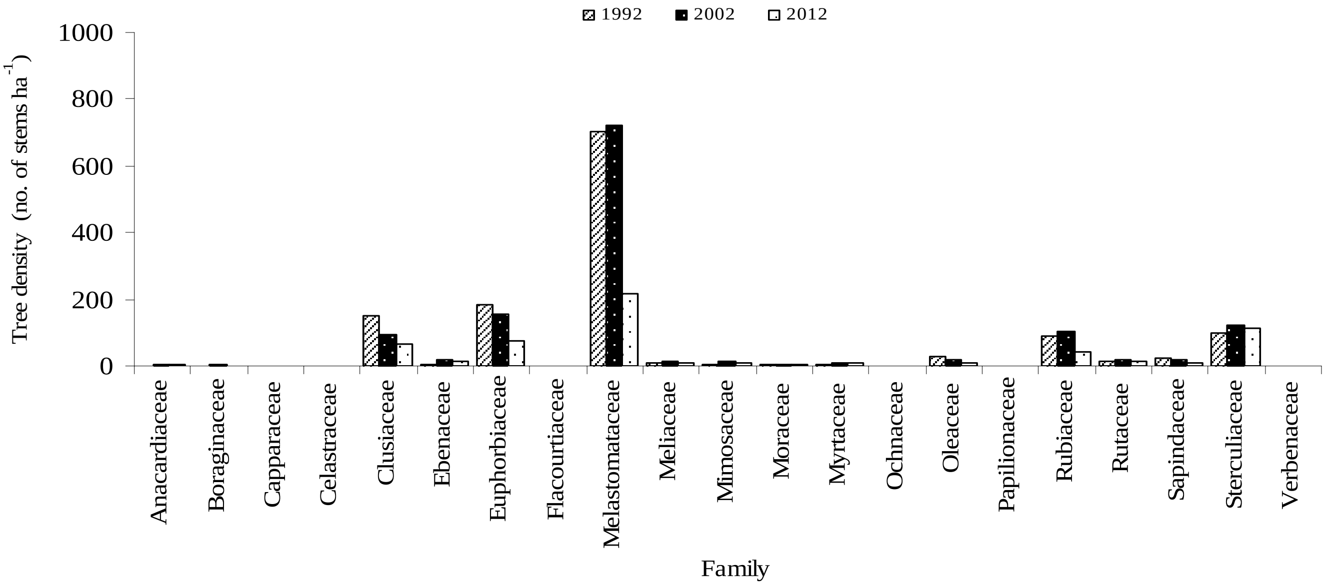

Fig. 1. Changes in family-wise tree density (stems ha^{-1}) during 1992 - 2012 period in tropical evergreen forest at Puthupet on the Coromandel Coast of India.

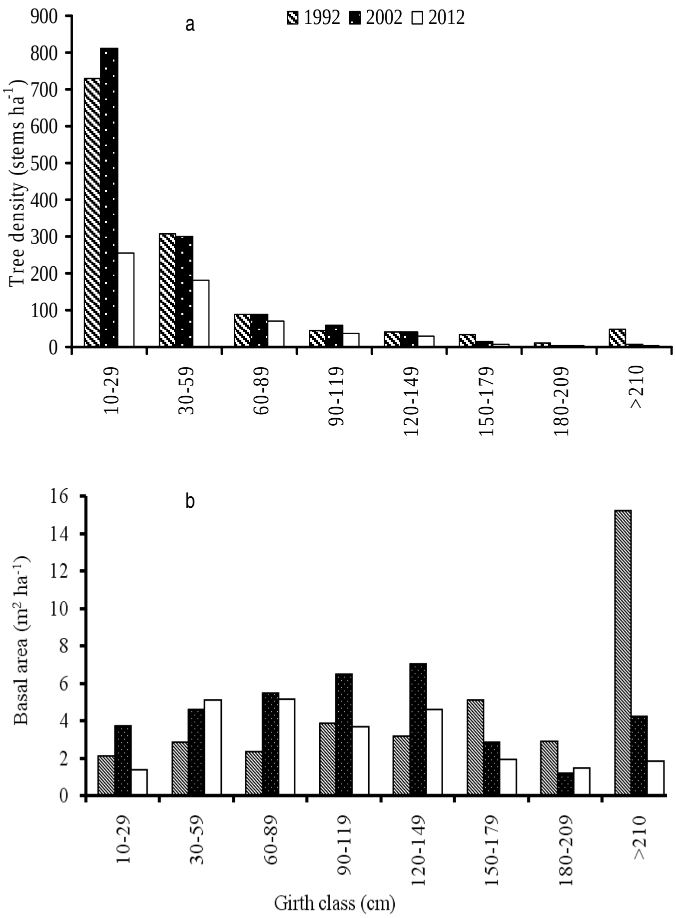

Fig. 2. Changes in girth class-wise (a) tree density (no. of stems ha^{-1}) and (b) basal area (m^2 ha^{-1}) during 1992 - 2012 period in tropical dry evergreen forest at Puthupet on the Coromandel Coast of India.

Over two decades, in the lower girth class of 10 - 30 cm, tree density declined by 68.7 %, which can be attributed to stem removal for fuel wood by local people, as smaller stems are convenient to cut and carry. Many previous studies (Clark & Clark 1984; Janzen 1970; Mani & Parthasarathy 2009; Newbery *et al.* 1999; Sundaram & Parthasarathy 2002) also reported that density of small trees decreased over time. Further, there is a consistent density decline in subsequent girth classes also (Fig. 2a). The tree density distribution among different girth classes and very low density in the lower girth classes as well as in the highest girth class showed the decreasing tendency of the forest in using the site resources, as Hitimana *et al.* (2004) also found a correlation between the distribution among diameter classes and site resourse utilisation efficiency of the forest.

In twenty years, the basal area of the forest decreased by 27.2 %. In the lower girth class (10 - 29 cm) it decreased by 63 % (Fig. 2b; from 1992 - 2012). This can be attributed to the poor regeneration of forest due to regular cutting of seedlings and trees with lower girth sizes (Mani & Parthasarathy 2009). As is evident from Fig. 2b, in 30 - 59 cm size class, there was a marginal increase in basal area in twenty years from 4.58 m^2 ha^{-1} to 5.12 m^2 ha^{-1}. Study indicated a marked reduction in basal area of other girth classes, except for an increase by 25 % in 180 - 210 cm size class, possibly due to the recruitment from the lower girth class during the 20-year interval (Mani & Parthasarathy 2009).

The changes in species composition and stem density at the study site show an irregular trend with a peak in the second (2002) inventory, when both the stem density and species richness were maximum (1338 stems, 29 species ha^{-1}) as compared to the initial (1992) and the latest (2012) inventory. The present study reveals that the anthropogenic disturbance causes disruption of forest structure and alters the species composition, which may lead to reduction in tree species and density and finally drive the forest to extremely degraded stage. These facts clearly underline adoption of proper management policies for biological conservation of the study site. To achieve this goal, we suggest strengthening of conservation activities with involvement of local people by creating awareness on biodiversity and bioresource values and cultural traditions associated with the sacred grove and restoration of the degraded portion with native species to prevent further species loss.

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