Article

Short-term population dynamics of tree species in tropical forests at Kodayar in the Western Ghats of Tamil Nadu, India

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Abstract
The population dynamics of tree species were studied in both deciduous and evergreen forests at Kodayar in the Western Ghats of Tamil Nadu. The mortality of trees was less than the number of new recruits, resulting in a net gain in population density and basal area. The increase in net population density and basal area of tree species could be because of their entry into the adult stage from the already existing sapling and seedling bank. Greater mortality of juveniles than that of adults could be due to intense competition for limited available resources at the juvenile stage. The present study concludes that to a larger extent, the forest ecosystems here are at building phase. Long-term studies are needed to understand the regeneration niche.

Keywords regeneration; tree population dynamics; tree mortality; tree recruitment; Western Ghats.

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1 Introduction

A tropical forest is a complex and dynamic biotic community, which has a tremendous power of self maintenance through regeneration. In trees, as in almost all organisms, mortality is high in the early stages of life, so that the selection of survivors and the determination of species composition of the forest operate most strongly in young plants; hence the importance of the regeneration “niche” (Grubb, 1977) and the ecologist’s interest are majorly focused in recording short-term changes in population of seedlings and saplings (Swaine and Hall, 1988). Recruitment of viable seeds, their germination, seedling establishment and seedling growth are indicators of the regeneration potential of a plant community. Several long-term studies of tree population dynamics were available in both tropical and temperate forests (Lieberman and Lieberman, 1987; Manokaran and Kochummen, 1987; Hubbell and Foster, 1992; Sukumar et al., 1992; Korning and Henrik, 1994; Condit, 1995; Bhat et al., 2000; Lwanga et al., 2000; Sheil et al., 2000; Rees et al., 2001; Battles et al., 2003; Takahashi et al., 2003; Nagamatsu et al., 2003; Fashing et al., 2004; Phillips et al., 2004: Kariuki et al., 2006) whereas short-term dynamics of tree populations were reported in few forest ecosystems (Manokaran et al., 1992; Hubbell and Foster, 1992; Homma et al., 2003; Miura and Yamamoto, 2003). However, studies on juvenile tree population dynamics in forest ecosystems in the Western Ghats are very few (Sukumar et al., 1992; Bhat et al., 2000).

Western Ghats of India, because of its geographical location, stable geological history, equable climate, has heavy rainfall and good soil conditions which supports a variety of tropical forest ecosystems. Phyto-geographically these forests are rich, not only with high species diversity but also with several palaeo-endemic species which are botanically a "relict" of an ancient and unique vegetation (Champion and Seth, 1968). During the last few decades these forests were subjected to unscientific exploitation particularly for agriculture, construction of hydro-electric project, raising monoculture plantations (*Hevea braziliensis* M. Arg.- Rubber, *Acacia mangium* - Acacia and *Tectona grandis* L. - Teak) and other developmental activities. Regeneration in many Indian forests, including the forests of Western Ghats, is inadequate to replace the adults (Sukumar et al., 1992). Therefore, in the present study an emphasis was laid to understand the regeneration niche with reference to community dynamics.

Successful conservation of these forest will ultimately depend upon an understanding of forest ecosystem dynamics (Sussman and Rakotozafy, 1994). The ever increasing demand for forest products and forest land, together with the alarming rate of population growth has put the remaining patches of forests on the verge of extinction (Bekele, 1994). A detailed quantitative and qualitative description and regeneration status of the remaining forests are necessary and timely as it will form the basis for future plans to manage and restore these vanishing resources. As part of an integrated research project, a general hypothesis was framed to test the effect of regeneration niche on species composition and ecosystem structure in tropical forest at Kodayar. The evergreen forests are transformed into semi-evergreen and moist deciduous forests because of various biotic and abiotic stresses. Therefore, the present study intends to study the short-term population dynamics of trees (>10 cm GBH; >3 cm DBH) over a three year period.

2 Materials and Methods

2.1 Study area

The study area at Kodayar, tropical forests here comes under the administrative division of Veerapuli and Kalamalai reserve forest and falls within the range of Agastyamalai biosphere reserve, is also one of the hot spots of biodiversity centers in India. Kani tribes (local tribals) are part of the ecosystem here. This forest area has 30 Kani settlements which occupy an area of 6.85 Km^2. It is located 400 Km south of Madurai (77°15' E, 8°29' N) and it is at 250-650 m elevation in the Kanyakumari district of Tamil Nadu, South India (Fig. 1). The mean annual rainfall (from south west and north east monsoon) recorded in the study sites was 2338 mm, of which 81% occurred from June to November (Fig. 2). December to March represents a brief dry period. Average monthly maximum and minimum temperatures were 30°C and 26°C in summer and 28°C and 24°C in winter, respectively.

Four different study sites (two each in deciduous forest closer to the village (250 m MSL) and subjected to anthropogenic pressures, and evergreen forest (500 - 650 m MSL)) were selected at Kodayar forest ecosystem for the present study (Table 1). Each study site had divided in to three sub-sites. The species that dominate in site I are *Terminalia paniculata* Roth, *Careya arborea* Roxb., *Buchanania lanzan* Spr., *Emblica officinalis* Gartner, *Dillenia pentagyna* Roxb., *Pterocarpus marsupium* Roxb. and *T. arjuna* W. & A (Table 2). The herbaceous community is mostly dominated by monocotyledons such as *Themeda cymbaria* Hack., *Themeda* sp., *Globba orixensis* Roxb., *Imperata cylindrica* Dur. & Sch. and *Thespesia lampas* Dalz. Site I has been subjected to annual wild fire. Site II is dominated by *T. paniculata* followed by *Aporosa lindleyana* Baill. and *Xanthophyllum flavescens* Roxb. Understorey vegetation is dominated by dicotyledon species such as

Helicteres isora L. and *Chromolaena odoratum* L. Site II has also been subjected to anthropogenic perturbations. Site III and IV are undisturbed evergreen forests. The species that dominate these sites are *Hopea parviflora* Bedd., *Syzygium laetum* Gandhi, followed by *Artocarpus heterophyllus* Lam., *Ixora brachiata* Roxb., *Syzygium* sp., *Vateria indica* L. and *Xanthophyllum flavescens* Roxb. Understorey vegetation was dominated by *Psychotria nigra* L., *Psychotria* sp. *Calamus* sp., *Memecylon* sp. and *Isonandra lanceolata* W. The contribution of grasses is much lower in site III and IV than in other sites except under open canopies. The species composition was also varied and dominated by *Oplismenus compositus* Beauv., *Panicum* sp. etc. under open canopies in the evergreen forests.

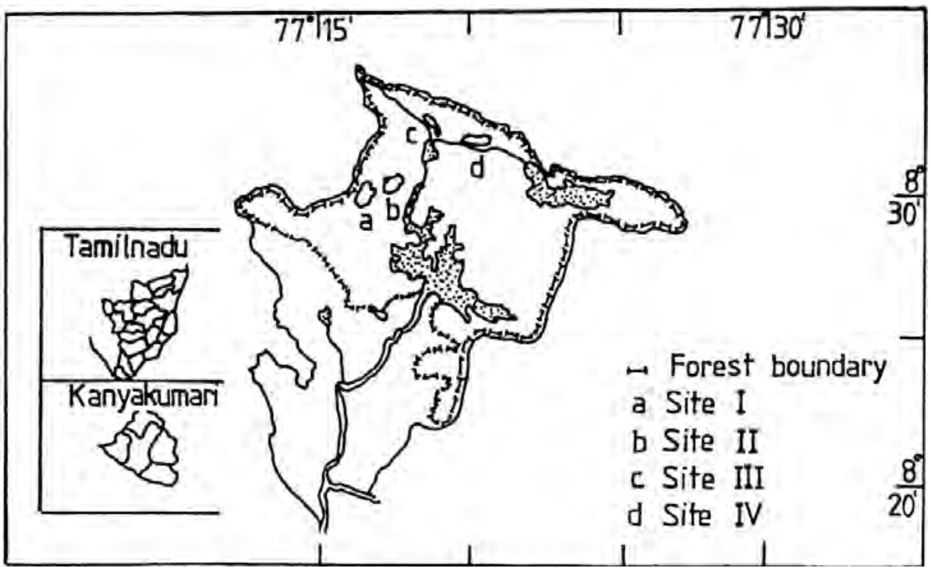

Fig. 1 Map of the study area showing location of the study.

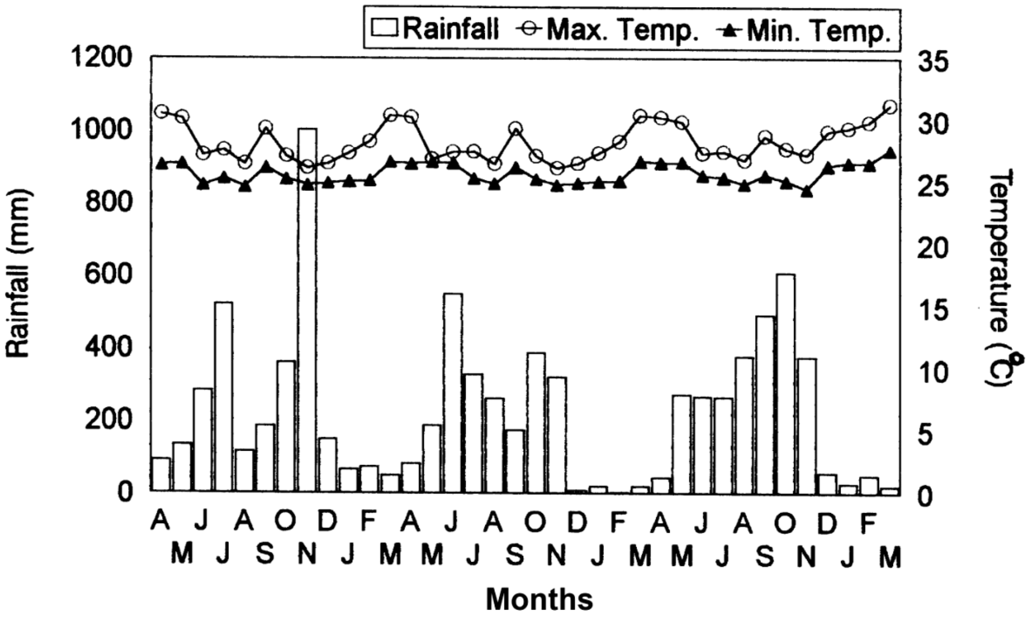

Fig. 2 Temperature and rainfall pattern for the study area at Kodayar in the Western Ghats of Tamil Nadu.

Table 1 Stand characteristics of deciduous (site I and II) and evergreen (III and IV) tropical forest sites at Kodayar in the Western Ghats of Tamil Nadu.

Criteria	Site I	Site II	Site III	Site IV
Number of species*	58	77	125	158
Number of tree (>10 cm DBH) species	15	22	37	45
Tree density (>10 cm DBH) (No./ha)	450	352	748	862
Basal area of trees (m^2/ha)	28.05	33.77	81.38	90.44
Species type				
Evergreen species	3	11	37	43
Species diversity index (tree)	2.20	2.37	2.65	2.61
Dominance index (tree)	0.142	0.157	0.146	0.153
Species richness (tree)	3.87	5.80	9.14	7.61
Evenness index (tree)	1.87	1.77	1.69	1.58
Level of disturbances	Very high (Fire)	Moderate	Little	Little

*includes trees, shrubs, herbs and all climbers in the study sites (0.5 ha in all the study sites except site III - 0.25 ha)

Table 2 Phytosociological analysis of tree community (> 10 cm DBH; values based on 50 quadrats of 10 x 10 m in all the study sites except for site III- 25 quadrats) in the deciduous (site I and II) and evergreen (III and IV) tropical forest sites at Kodayar in the Western Ghats of Tamil Nadu. D - density; B.A. - basal area.

Name of the species	Site I		Site II		Site III		Site IV	
	D No/ha	B.A m^2/ha	D No/ha	B.A. m^2/ha	D No/ha	B.A. m^2/ha	D No/ha	B.A. m^2/ha
Aglaia barberi Gamble	-	-	-	-	-	-	2	0.03
Antiaris toxicaria Leach.	-	-	-	-	-	-	2	0.06
Antidesma zeylanicum Lam.	-	-	-	-	4	0.04	2	0.05
Aporosa lindleyana Baill.	-	-	52	3.57	-	-	-	-
Artocarpus heterophyllus Lam.	-	-	-	-	4	0.30	6	2.42
A. hirsutus Lam.	-	-	4	0.13	-	-	-	-
Baccaurea courtallenssis M. Arg.	-	-	-	-	-	-	2	0.07
Beilschmiedia gemmiflora Kosterm.	-	-	-	-	4	0.80	-	-
Berrya cordifolia (Willd.) Burret.	-	-	4	0.03	-	-	4	0.62
Bridelia crenulata Roxb.	14	0.19	-	-	-	-	-	-
Buchanania lanzan Spr.	74	2.53	-	-	-	-	-	-
Calophyllum polyanthum Wall. Ex Choisy	-	-	-	-	4	0.09	-	-
Carallia brachiata (Lour.) Merr.	-	-	-	-	-	-	32	8.56
Careya arborea Roxb.	52	2.42	12	1.05	-	-	-	-
Canthium curtalensis	-	-	-	-	4	0.03	-	-
C. malabarica	-	-	-	-	8	0.10	-	-
Cullenia excelsa Wt.	-	-	-	-	4	1.27	-	-
Cycas sp.	2	0.07	-	-	-	-	-	-

Dalbergia latifolia Roxb.	-	-	4	0.49	-	-	-	-
Dillenia pentagyna Roxb.	42	1.90	8	0.70	-	-	-	-
Dimocarpus longan Lour.	-	-	4	0.03	8	0.20	16	0.67
Diospyros bourdilloni Brandis	-	-	-	-	32	1.65	16	1.11
D. paniculata Dalz.	-	-	-	-	-	-	14	0.60
Dipterocarpus indicus Bedd.	-	-	-	-	8	2.86	-	-
Dysexylum beddomi	-	-	-	-	-	-	2	0.16
Emblica officinalis Gaertn.	42	0.68	4	0.07	-	-	-	-
Eugenia thwaitesii Duthie	-	-	-	-	4	1.21	2	0.12
Ficus hispida L.f.	-	-	-	-	-	-	2	0.55
Ficus sp.	-	-	8	0.09	-	-	-	-
Garcinia travancorica Bedd.	-	-	-	-	4	0.26	4	0.36
Gluta travancorica Bedd.	-	-	-	-	48	3.73	-	-
Gomphandra tetrandra Sleumer	-	-	-	-	20	1.84	6	0.72
Gordonia obtusa	-	-	-	-	8	0.62	-	-
Grewia tiliaefolia Vahl.	-	-	8	0.06	-	-	-	-
Holarrhena sp.	-	-	44	1.23	-	-	-	-
Hopea parviflora Bedd.	-	-	-	-	244	42.9	334	41.3
Hopea sp.	-	-	-	-	-	-	2	0.03
Hunteria corymbosa Roxb.	-	-	-	-	4	0.26	14	0.80
Hydnocarpus alpina Wt.	-	-	-	-	-	-	2	0.04
Hymenodictyon orixense (Roxb.) Mabb.	-	-	4	0.03	-	-	-	-
Ixora brachiata Roxb.	-	-	28	1.00	48	0.99	70	4.25
Ixora sp.	-	-	-	-	-	-	2	0.05
Kingiodendron pinnatum Harms	-	-	-	-	-	-	10	0.24
Litsea laevigata (Nees)Gamble	-	-	-	-	4	0.11	2	0.04
Macaranga peltata (Roxb.) Mueller	-	-	4	0.43	-	-	-	-
Mallotus philippensis M.Arg.	-	-	-	-	-	-	12	0.44
Mangifera indica L.	-	-	-	-	8	0.29	2	0.07
Mesua ferrea L.	-	-	-	-	4	0.05	2	0.05
Myristica dactyloides Gaertn.	-	-	-	-	24	0.56	-	-
Neolitsea zeylanica (Nees) Merr.	-	-	-	-	-	-	6	0.45
Odina wodier Roxb.	-	-	-	-	-	-	4	1.25
Olea dioica Roxb.	-	-	-	-	4	0.18	-	-
Phaeanthus malabaricus Bedd.	-	-	-	-	4	0.04	-	-
Polyalthia wightii Thw.	2	0.03	12	2.03	-	-	-	-
Prunus ceylanica (Wt.) Miq.	-	-	-	-	-	-	4	0.36
Pterocarpus marsupium Roxb.	36	6.36	-	-	-	-	-	-
Pterospermum diversifolium Bl.	-	-	-	-	-	-	4	0.36
P. rubiginosum W. &Arn.	-	-	-	-	-	-	4	0.15
Sapindus emarginatus Vahl.	-	-	4	0.38	-	-	-	-
Schleichera oleosa (Lour.) Oken.	-	-	4	0.44	-	-	-	-
Scolopia crenata (W. & A.) Clos.	-	-	-	-	4	0.03	14	4.98
Stereospermum personatum (Hassk.) Chatterjee	-	-	-	-	4	0.02	14	3.10
Syzygium laetum Gandhi	-	-	-	-	12	0.32	148	7.64
S. gardneri Thw.	-	-	-	-	-	-	10	0.50
S. mundagam (Bourd.) Chithira	-	-	-	-	12	0.21	2	0.19
Syzygium sp.	-	-	-	-	-	-	4	0.12

Tabernaemontana heyneana Wall.	-	-	4	0.47	-	-	2	0.07
Terminalia arjuna W. & A.	24	1.96	-	-	-	-	-	-
T. chebula Retz.	26	0.72	-	-	-	-	-	-
T. crenulata Roxb.	6	0.84	-	-	-	-	-	-
T. paniculata Roth.	120	9.45	80	20.13	-	-	-	-
T. tomentosa W. & A.	4	0.48	-	-	-	-	-	-
Tricalysia apiocarpa Gamble	-	-	-	-	4	0.04	-	-
Vateria indica L.	-	-	-	-	80	10.8	-	-
Vitex altissima L.	-	-	-	-	32	2.88	28	2.77
Xanthophyllum flavescens Roxb.	-	-	24	0.98	40	2.36	14	1.44
Others	6 (2)	0.31	36 (2)	0.40	52 (5)	4.31	30 (5)	3.05

Values in the parentheses represent unidentified species in the study sites.

2.2 Methods

Thirty randomly located 10 m × 10 m study plots (permanent quadrats; 10 in each sub-site) were established in all the study sites. All the living trees (≥10 cm GBH- Girth at breast height) were tagged, identified and measured the girth at 1.3 m (breast) height. All the study plots (permanent quadrats) were recensused after three years. In second census (after three years from the initial census) new recruits into the ≥10 cm GBH categories were also taken into account. The diameter increment, mortality and recruitment of trees were calculated based on initial and final census data (Lieberman et al., 1985; Manokaran et al., 1992).

Percentage of annual mortality was calculated as (Sheil et al., 1995):

Annual mortality (%) = (1- (Nt/No)*(1/ny))* 100%

where Nt = number of survivors at time t, No = original number of trees, ny = number of years between samples.

One way ANOVA was used to find out significant differences among the sites in the density of the soil seed bank and the mortality and recruitment rates of trees.

Table 3 Population dynamics of tree species in the deciduous (site I and II) and evergreen (III and IV) tropical forest sites at Kodayar in the Western Ghats of Tamil Nadu.

Criteria	Site I	Site II	Site III	Site IV	Sig. level
Density					
Total number of trees (>10 cm GBH) at the beginning of the study period trees/ha	740^a	570^a	1320^b	1530^b	***
Total number of trees (>10 cm GBH) at the end of the study period trees/ha	810^a	660^a	1370^b	1700^c	***
Number of dead trees during the three years study period trees/ha	80^a	50^b	220^c	240^c	**
Number of newly recruited trees during the three years study period	150^a	140^a	270^b	410^c	***
Basal Area					
Basal area (m^2/ha) at the beginning of the					

study period[A]	30.4^{a}	30.2^{a}	81.8^{b}	107^{c}	***
Basal area (m^2/ha) of dead trees during three years study period[B]	2.7^{a} (8.9%)	0.9^{b} (3 %)	7.8^{c}(9.5%)	8.7^{c}(8.11 %)	***
Basal area (m^2/ha) of new recruits during the three years study period[C]	0.42^{a} (1.4 %)	0.41^{a} (1.4%)	1.08^{b}(1.3%)	1.86^{c} (1.7%)	***
Increase in basal area (m^2/ha) of existing survival species [D]	4.4^{a} (14.5%)	3.3^{a} (10.9%)	7.7^{b}(9.4%)	12.8^{c} (11.9%)	***
Basal area (m^2/ ha) at the end of the study period. A-B+C+D	32.52^{a}	33.01^{a}	82.88^{b}	112.96^{c}	***

Different letter(s) on the same rows indicates significant differences; *** P<0.01, ** P<0.05

3 Results

Population dynamics and structural attributes of trees in all the study sites are given in Table 3. Evergreen forest sites (III & IV) had significantly (P< 0.05) greater density and basal area per hectare than deciduous forest sites (I & II). Similar trends were observed for mortality and recruitment in these sites. Mortality was lower in all the study sites than recruitments. As a result, there was a net gain in population density over three years. Similarly an increase in basal area per hectare also was observed.

Table 4 Tree (>10 cm GBH) population dynamics (recruits and deaths during three years study period) in the deciduous (site I and II) tropical forest sites at Kodayar in the Western Ghats of Tamil Nadu.

Name of the species	Site I					Site II				
	A	B	C	D	E	A	B	C	D	E
Alstonia scholaris	-	-	-	-	-	10	10	-	-	10
Aporosa lindleyana	-	-	-	10	10	70	60	14	10	70
Artocarpus hirsutus	-	-	-	-	-	10	10	-	-	10
Buchanania lanzan	140	130	7	30	160	-	-	-	-	-
Bridelia crenulata	20	10	50	10	20	-	-	-	-	-
Careya arborea	70	60	14	20	80	10	10	-	-	10
Cassia fistula	10	10	-	-	10	-	-	-	-	-
Cycas sp.	10	10	-	-	10	-	-	-	-	-
Dalbergia latifolia	-	-	-	-	-	10	10	-	-	10
Dillenia pentagyna	60	50	17	10	60	10	10	-	-	10
Dimocarpus longan	-	-	-	-	-	10	10	-	10	20
Emblica officinalis	110	100	9	10	110	-	-	-	-	-
Ficus sp.	-	-	-	-	-	10	10	-	-	10
Grewia tiliaefolia	-	-	-	-	-	10	10	-	10	20
Helicteres isora	-	-	-	-	-	200	170	15	70	240
Holarrhena pubscens	-	-	-	-	-	50	40	20	10	50
Ixora brachiata	-	-	-	-	-	30	30	-	10	40
Macaranga peltata	-	-	-	-	-	10	10	-	-	10
Mallotus philippensis	-	-	-	-	-	-	-	-	10	10

Olea dioica	20	10	50	10	20	-	-	-	-	-
Phoenix sylvestris	10	10	-	-	10	-	-	-	-	-
Polyalthia sp.	10	10	-	10	20	10	10	-	-	10
Pterocarpus marsupium	30	30	-	10	40	-	-	-	-	-
Sapindus emarginatus	-	-	-	-	-	10	10	-	-	10
Schleichera oleosa	-	-	-	-	-	10	10	-	-	10
Terminalia arjuna	20	20	-	10	30	-	-	-	-	-
T. chebula	30	30	-	10	40	-	-	-	-	-
T. paniculata	160	150	6	10	160	60	60	-	-	60
T. tomentosa	10	10	-	-	10	-	-	-	-	-
Terminalia sp.	10	10	-	-	10	-	-	-	-	-
Xanthophyllum flavescens	-	-	-	-	-	30	30	-	10	40
Others	20	10	50	-	10	10	10	-	-	10

A= Initial Density (No./ha); B = Density (No./ha) at recensus (survival of tagged trees); C = Mortality (%); D = New recruits (No./ha); E = Final density (No./ha).

Table 4 and 5 showed the contribution of individual species to total tree population structure in all the study sites. *T. paniculata* and *B. lanzan* showed greater density in site I, while in site II, *H. isora, A. lindleyana* and *T. paniculata* showed greater density. However, in evergreen forest sites (III & IV), *H. parviflora, Syzygium laetum, I. brachiata, V. indica, X. flavescens* and *Gluta travancorica* showed greater density. *I. brachiata, Ficus, Olea dioica, D. longan* and *X. flavescens* were common species found in both deciduous and evergreen sites. Percentage of mortality was significantly ($P<0.05$) greater in evergreen forest (16.67% in site III; 15.69% in site IV) than in deciduous forests (10.81% in site I; 8.77% in site II). Percentage of mortality of trees ranged from 4.5 in *H. parviflora* to 66.7% in *Orophea erythrocarpa. Bredelia crenulata, O. dioica, Nothopegia travancorica, O. erythrocarpa, Agrostistachys indica, Antidesma zeylanicum, Ficus sp.*, *H. alpina*, *I. lanceolata* and *Syzygium* sp. had high rates mortality (≥50%) whereas species with greater densities such as *B. lanzan, E. officinalis, T. paniculata, S. laetum, I. brachiata* and *H. parviflora* had lower rates mortality (≤10%). However, no mortality was observed in 9 species in site I, 16 species in site II, 11 species in site III and 17 species in site IV during the three year study period.

Table 5 Tree (>10 cm GBH) population dynamics (recruits and deaths during three years study period) in the evergreen (site III and IV) tropical forest sites at Kodayar in the Western Ghats of Tamil Nadu.

Name of the species	Site III					Site IV				
	A	B	C	D	E	A	B	C	D	E
Aglaia barberi	-	-	-	-	-	10	10	-	10	20
Agrostistachys indica	-	-	-	-	-	20	10	50	20	30
Alstonia scholaris	-	-	-	10	10	-	-	-	10	10
Antidesma zeylanicum	-	-	-	-	-	20	10	50	-	10
Artocarpus hirsutus	10	10	-	-	10	10	10	-	-	10
Baccaurea courtallensis	-	-	-	10	10	10	10	-	-	10
Canthium dicoccum	-	-	-	-	-	-	-	-	10	10
Chionanthus malabaricus	30	20	33	10	30	10	10	-	-	10
C. leprocarpa	-	-	-	-	-	30	20	33	-	20
Dimocarpus longan	30	20	33	10	30	10	10	-	10	20
Diospyros sp.	50	40	20	10	50	40	30	25	10	40
Diospyros pruriens	-	-	-	-	-	40	40	-	-	40

Dipterocarpus indicus	10	10	-	-	10	-	-	-	-	-
Eugenia sp.	-	-	-	-	-	-	-	-	10	10
Ficus sp.	-	-	-	-	-	20	10	50	10	20
Garcinia travancorica	10	10	-	-	10	-	-	-	-	-
Gluta travancorica	100	70	30	20	90	-	-	-	-	-
Gomphandra tetrandra	40	20	50	20	40	10	10	-	10	20
Hopea parviflora	300	270	10	-	270	220	210	5	-	210
Hopea sp.	-	-	-	20	20	10	10	-	10	20
Hydnocarpus alpina	10	10	-	-	10	20	10	50	20	30
Isonandra lanceolata	-	-	-	10	10	20	10	50	10	20
Ixora brachiata	120	100	17	10	110	170	150	12	20	170
Ixora sp.	-	-	-	-	-	-	-	-	20	20
Kingiodendron pinnatum	-	-	-	20	20	10	10	-	-	10
Lepisanthes decipiens	-	-	-	-	-	-	-	-	10	10
Mallotus philippensis	-	-	-	10	10	20	10	50	-	10
Mangifera indica	10	10	-	-	10	-	-	-	-	-
Measua ferrea	20	20	-	10	30	30	20	33	10	30
Myristica dactyloides	50	40	20	10	50	-	-	-	-	-
M. malabarica	-	-	-	-	-	10	10	-	-	10
Neolitsea zeylanica	-	-	-	-	-	10	10	-	-	10
Nothopegia travancorica	20	10	50	10	20	-	-	-	-	-
Olea dioica	10	10	-	-	10	-	-	-	-	-
Orophea erythrocarpa	30	10	67	10	20	20	10	50	10	20
Phaeanthus malabaricus	10	10	-	-	10	70	60	14	20	80
Prunus ceylanica	-	-	-	-	-	30	20	33	10	30
Psychotria sp.	-	-	-	-	-	50	30	40	50	80
Pterospermum diversifolium	-	-	-	-	-	10	10	-	-	10
P. rubiginosum	-	-	-	-	-	10	10	-	-	10
Scolopia crenata	10	10	-	10	20	30	20	33	10	30
Stereospermum personatum	-	-	-	-	-	10	10	-	-	10
Syzygium gardneri	-	-	-	-	-	10	10	-	-	10
S. laetum	10	10	-	10	20	280	260	7	30	290
S. mundagam	20	20	-	-	20	10	10	-	10	20
Syzygium sp.	-	-	-	-	-	20	10	50	10	20
Vateria indica	120	100	17	10	110	-	-	-	-	-
Vitex altissima	50	40	20	-	40	30	30	-	-	30
Xanthophyllum flavescens	110	100	9	20	120	60	50	17	30	80
Others	140	130	7	20	150	140	120	14	30	150

A = Initial density (No./ha); B = Density (No./ha) at recensus (survival of tagged trees); C = Mortality (%); D = New recruits (No./ha); E = Final density (No./ha).

Recruitment of juveniles (>10 cm GBH- < 30 cm GBH) were significantly (P<0.01) greater in evergreen forests than in deciduous forests (Tables 3, 4, and 5). The species with greater tree density such as *T. paniculata* and *E. officinalis* (site I), *I. brachiata* and *V. indica* (Site III & IV) showed poor regeneration (≤ 11.8%). Even though *H. parviflora* had greater density (site III & IV), no juveniles were found during the study period. *A. lindleyana* and *M. philippensis* were new recruits in site I and II respectively. However, the adults of these were not accounted in the initial census. There was no recruitment of 6 species in site I, 12 species in site II, 10 species in site III and 15 species in site IV.

Tree population showed an increase in density per ha after three years in the second census. Net change in population size remains the same for 9 species in site I, 14 species in site II, 14 species in site III and 21 species in site IV. An increase in population size was recorded for 7 species in site I, 5 species in site II and 5 species in site III and 12 species in site IV whereas reduction in net change in population size was accounted for one species in site I, 6 species in site III and 3 species in site IV. In all the study sites the percentage of mortality was low but recruitment was moderately higher.

The mortality of tree species in two size classes is presented in Table 6. In general, smaller trees (tree sapling stage; >3 cm **-** <10 cm DBH) had greater mortality rates than larger trees. Larger trees (>10 cm DBH) such as *Ficus* sp., *Mesua ferrea, V. indica* and one unidentified tree died during the study period. The dominant tree species in evergreen forests such as *G. travancorica, H. parviflora, I. Brachiata, Psychotria* sp. and *S. laetum* showed a high percentage of mortality at the juvenile stage.

Table 6 Percentage mortality of tree species in two size classes (A = saplings >3-<10 cm DBH; B = Trees >10 cm DBH) in the deciduous (site I and II) and evergreen (III and IV) tropical forest sites at Kodayar in the Western Ghats of Tamil Nadu.

Species	Site I		Site II		Site III		Site IV	
	A	B	A	B	A	B	A	B
Agrostistachys indica	-	-	-	-	-	-	4.2	-
Antidesma zeylanicum	-	-	-	-	-	-	4.2	-
Aporosa lindleyana	-	-	20	-	-	-	-	-
Bridelia crenulata	12.5	-	-	-	-	-	-	-
Buchanania lanzan	12.5	-	-	-	-	-	-	-
Chionanthus malabaricus	-	-	-	-	4.5	-	-	-
C. leprocarpa	-	-	-	-	-	-	4.2	-
Careya arborea	12.5	-	-	-	-	-	-	-
Dillenia pentagyna	12.5	-	-	-	-	-	-	-
Dimocarpus longan	-	-	-	-	4.5	-	-	-
Diospyros sp.	-	-	-	-	4.5	-	4.2	-
Emblica officinalis	12.5	-	-	-	-	-	-	-
Ficus sp.	-	-	-	-	-	-	-	4.2
Gluta travancorica	-	-	-	-	13.6	-	-	-
Gomphandra tetrandra	-	-	-	-	9.1	-	-	-
Helicteres isora	-	-	60	-	-	-	-	-
Holarrhena pubescens	-	-	20	-	-	-	-	-
Hopea parviflora	-	-	-	-	13.6	-	4.2	-
Hydnocarpus alpina	-	-	-	-	-	-	4.2	-
Isonandra lanceolata	-	-	-	-	-	-	4.2	-
Ixora brachiata	-	-	-	-	9.1	-	8.3	-
Mallotus philippensis	-	-	-	-	-	-	4.2	-
Mesua ferrea	-	-	-	-	-	-	-	4.2
Myristica dactyloides	-	-	-	-	4.5	-	-	-
Nothopegia travancorica	-	-	-	-	4.5	-	-	-
0lea dioica	12.5	-	-	-	-	-	-	-
Orophea erythrocarpa	-	-	-	-	4.5	4.5	4.2	-
Phaeanthus malabaricus	-	-	-	-	-	-	4.2	-
Prunus ceylanica	-	-	-	-	-	-	4.2	-
Psychotria sp.	-	-	-	-	-	-	8.3	-
Scolopia crenata	-	-	-	-	-	-	4.2	-

Syzygium laetum	-	-	-	-	-	-	8.3	-
Syzygium sp.	-	-	-	-	-	-	4.2	-
Terminalia paniculata	12.5	-	-	-	-	-	-	-
Vateria indica	-	-	-	-	4.5	4.5	-	-
Vitex altissima	-	-	-	-	4.5	-	-	-
Xanthophyllum flavescens	-	-	-	-	4.5	-	4.2	-
Others	-	12.5	-	-	4.5	-	8.3	-

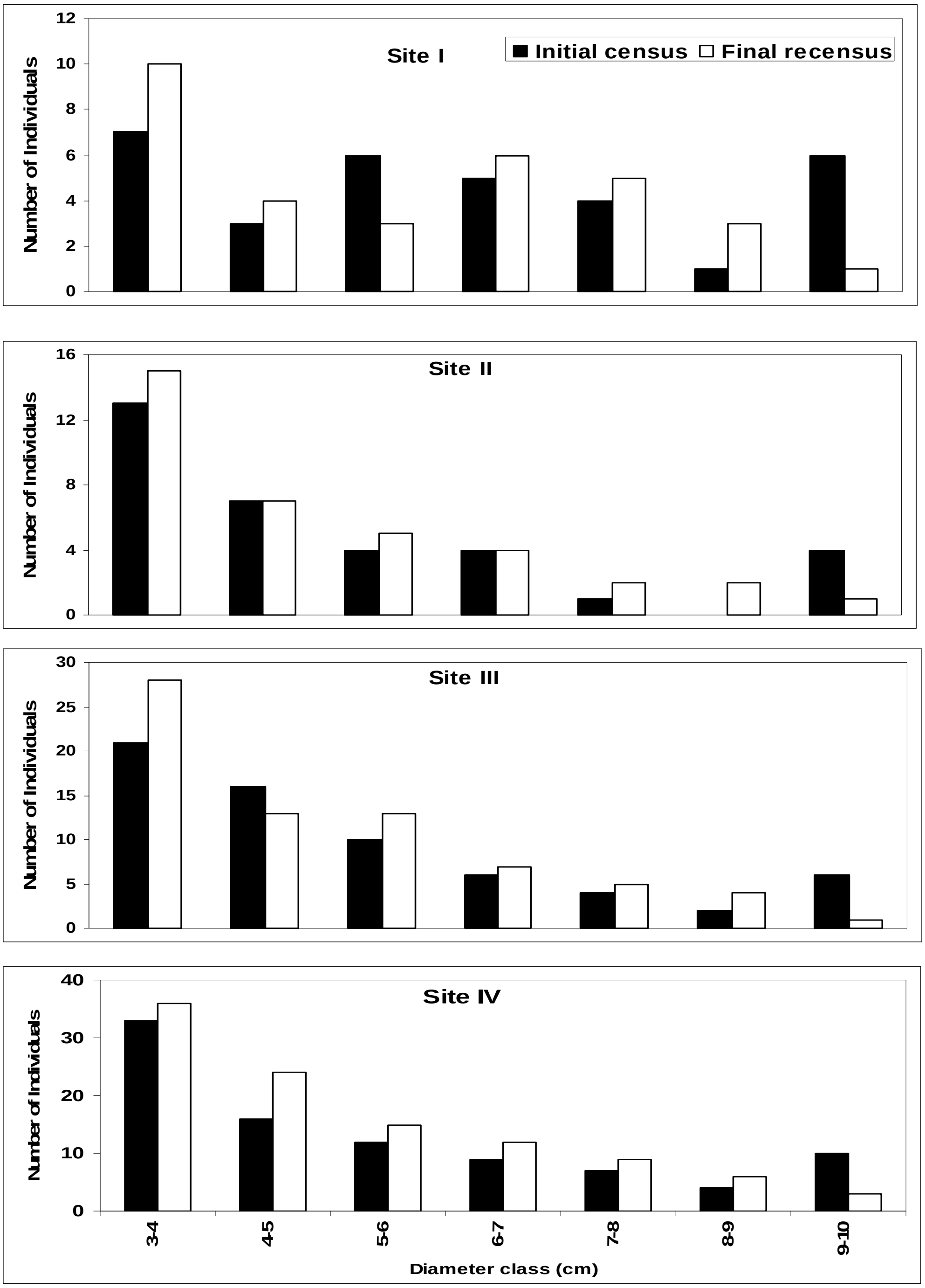

Fig. 3 Size class distribution of initial census and recensus (after three years from the initial census) of juvenile (>3-<10 cm DBH) population in tropical forests at Kodayar in the Western Ghats of Tamil Nadu.

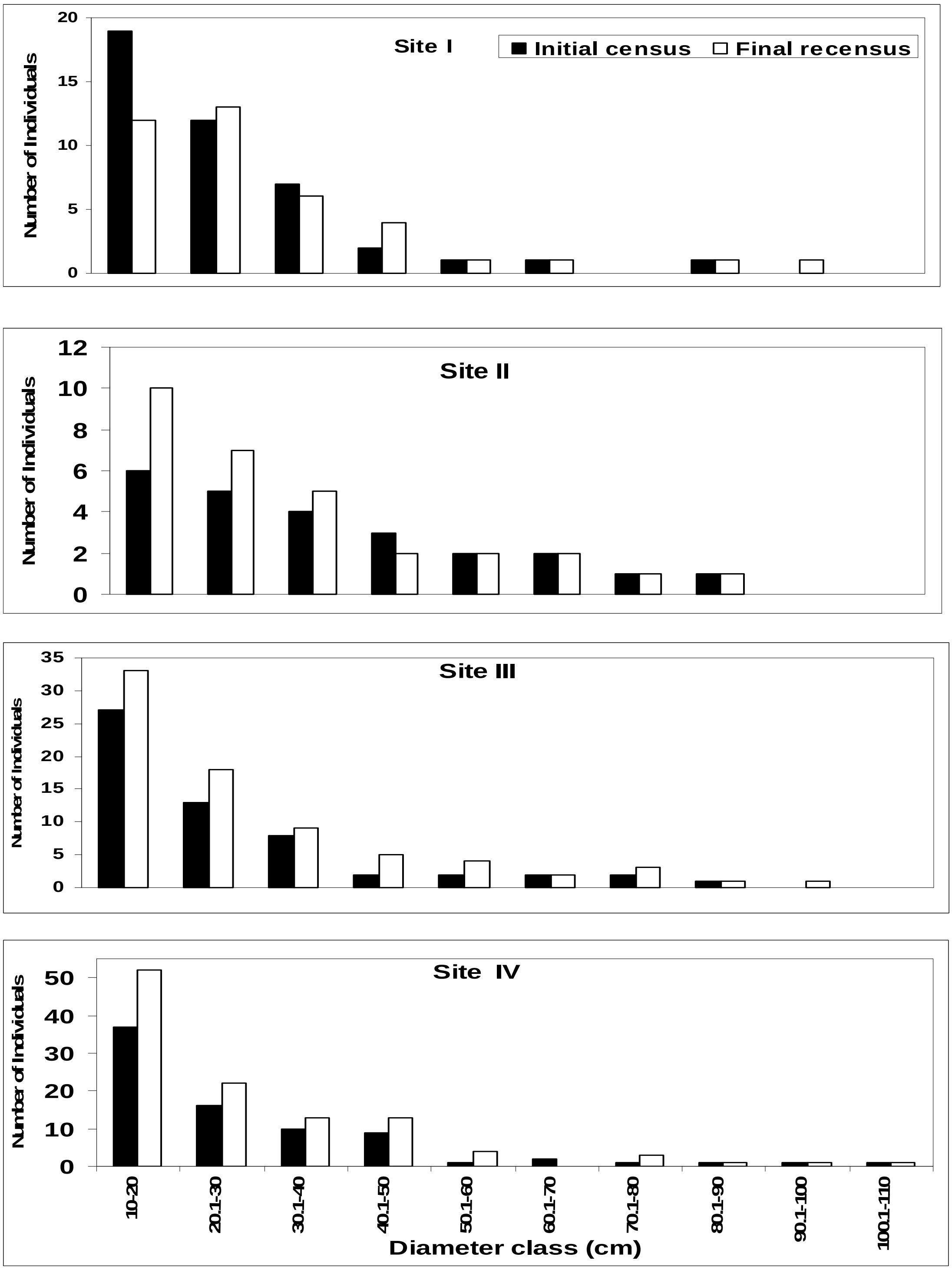

Fig. 4 Size class distribution of initial census and recensus (after three years from the initial census) of adults (>10 cm DBH) tree population in tropical forests at Kodayar in the Western Ghats of Tamil Nadu.

The size class distributions of the initial census and recensus (after three years from the initial census) are given in Fig. 3 and 4. The DBH distribution of tree species in both the deciduous and evergreen forests showed a “L” shaped curve. The DBH distribution of saplings (>3 cm - <10 cm DBH) also showed a similar pattern for both the forests except in site I. In all the study sites, the10-20 cm DBH size class increased from initial census to recensus. A decline of the 9-10 cm DBH size class was observed in all the study sites at the time of recensus. However, the 3-4 cm DBH size class distribution was comparatively greater at the time of final-recensus.

Percentage of mortality of juveniles and adult trees were significantly (P<0.05) greater in evergreen forest (site III & IV) than in deciduous forests (site I & II; Table 7). However, stand half-life values showed lower in evergreen forests compared to deciduous forests in case of both juvenile population and adult population.

Table 7 Comparative account of mortality rates of tropical forests sites (following Lieberman et al., 1985).

Study location	Plot area (ha)	Time interval	Mortality (%)	Annual Mortality (λ)	Percentage of Annual Mortality	Stand half-life $t_{(0.50)}$ Years	Source
La Selva Costarica	4 - 4.4	13	20.9 - 25.3	0.018 - 0.022*	-	31 - 39	Lieberman et al. (1985)
Kade, Ghana	2	12	19.8	0.018*	-	38	Swaine and Hall (1988)
Barro Colorado Island, Panama,							
Young forest	5	5	8.7	0.018*	-	53	Putz and Milton (1982)
Old forest	2	5	5.2	0.011*	-	68	
Bukit Lagong, Malaysia	1.6	10	12.3	0.013*	-	53	Wyatt-Smith (1966)
Sepilok, Malaysia	1.8	6	5.9	0.010*	-	68	Nicholson (1965)
Pasoh Forest Reserve, Malaysia							
All species	50	3	6.88	0.024	2.34	34.1	Manokaran et al. (1992)
21 common species	50	3	6.90	0.024	2.35	28.7	
Whole plot	50	3	3.81	0.013	1.28	53.2	
Western Ghats, Kodayar, India							
Site I	0.3	3	10.81	0.038	3.74	17.83	Present study
Site II	0.3	3	8.77	0.031	3.01	22.30	
Site III	0.3	3	16.67	0.061	5.89	11.06	
Site IV	0.3	3	15.69	0.060	5.21	11.84	
Pasoh Forest Reserve, Malaysia							
All species	50	3	7.63a	0.027a	2.60a	25.84a	
			4.08b	0.014b	1.38b	49.56b	Manokaran et al. (1992)
19 common species	50	3	7.68a	0.027a	2.63a	25.68a	
			4.16b	0.014b	1.40b	48.64b	
Whole plot	50	3	3.93a	0.014a	1.33a	51.55a	
			3.14b	0.011b	1.13b	60.79b	
Western Ghats, Kodayar, India							
Site I	0.3	3	24.1c	0.092c	8.79c	7.18c	
			2.2d	0.008d	0.75d	92.18d	Present study
Site II	0.3	3	22.9c	0.087c	8.31c	7.63c	
			-	-	-	-	
Site III	0.3	3	53.76c	0.143c	13.35c	4.48c	
			2.67d	0.009d	0.90d	76.38d	
Site IV	0.3	3	32.93c	0.133c	12.46c	4.91c	
			2.32d	0.010d	0.78d	88.23d	

*Annual mortality was calculated by using the formula $\lambda = \log e\ (N_o/N_1) / t$; where No = beginning population, N1 = end population, and t = time interval between the measurements. a = 1 - < 5 cm diameter class; b = >5 cm diameter class; c = >3 - < 10 cm diameter class; d = > 10 cm diameter class.

4 Discussion

One of the characteristic features of tropical forests is high species richness. Mean total number of tree species (≥10 cm GBH) recorded in the study plots (permanent quadrats) ranged 17-37 per 0.1 ha. This value is at the lower side of the ranges (20-223) given for wet evergreen forests (Proctor et al., 1983; Whitmore, 1975) and tropical forests in the Western Ghats (Pascal, 1988). The tree density (>10 cm DBH) and basal area recorded in the present study (permanent quadrats) are greater than those values reported by others (Campbell et al., 1986; Thompson et al., 1992; Rao and Mishra, 1994; Ganesh et al., 1996). This differences could be due to smaller sampling size, species composition, age and degree of disturbances (Sundarapandian and Swamy, 2000; Swamy et al., 2000).

Generally, plant recruitment and mortality depend upon variable climatic events. Germination and emergence of certain woody plants are episodic as it is observed in the present study. In the present study, mortality of trees was less than new recruitments resulting in net gains in population density and basal area over three years period. The increase in population density and basal area of tree species is because of the entry of juveniles from already existing saplings and seedlings (<3 cm DBH) into the adult (>10 cm DBH) phase as reported by Battles et al. (2003). The population structure, characterised by the presence of sufficient population of seedlings, saplings and adults recorded in the present study, indicates successful regeneration of forest tree species and the presence of saplings under the canopies of adult trees also indicates the future composition of a community (Saxena and Singh, 1984; Pokhriyal et al., 2010). Mortality was greater at the juvenile stage (>3 cm - < 10 cm DBH) than for adult trees (>10 cm DBH) in the present study. Annual mortality (λ) also showed a similar trend. Similar results were reported in Malaysian forests (Table 7; Kochummen et al., 1990; Manokaran et al., 1992). This pattern suggests that at the understorey level, competition for light is greatest and the juvenile tree population is highly vulnerable, but once stems attain a certain size, mortality rate declines (Uhl, 1982; Lieberman et al., 1985; Manokaran et al., 1992; Nascimento and Proctor, 1997). The comparison of annual mortality and stand half-life showed that the present study values are lie within the range of available reports (Table 7). However, variation in the values of annual mortality and half-life period among the studies available may be due to variations in stand size, census intervals and tree size classes taken into an account (Lewis et al., 2004).

Patterns of mortality and recruitment vary considerably from place to place over the same period. In the present study, both mortality and recruitment were greater in evergreen forests than in deciduous forests. Low recruitment in deciduous forest could be attributed to annual wild fires caused by human interference. For example, in the present study, site I had no adult of *Dalbergia latifolia*, but the juveniles appeared during the rainy season. This could be ascribed to persistent soil seed bank or immigration of seeds from neighbouring areas and also through vegetative reproduction (from the existing root suckers). However, the survivorship of these juveniles was very poor and also greatly affected by wild annual fires caused by anthropogenic perturbations (Boyer, 1974; Fairfax et al., 2009). Greater recruitments to compensate mortality resulted in a net gain of population in evergreen forest. This could be attributed to favourable micro-climatic conditions for better growth and survival of seedlings. Similarly net gain of 10% from initial population was observed in BCI (Hubbell and Foster, 1992).

Regeneration is the process of silvigenesis by which trees and forests survive over time (Bhuyan et al., 2003). Halle et al. (1978) proposed a unifying model of the sylvigenitic cycle, which describes a forest as a dynamic system with successional consequences of ever-changing composition and structure; a stable homeostatic phase is followed by a dynamic growing phase after smaller or larger breakdowns of forest structure. The present study concludes that these forests at Kodayar are at a building phase, largely in areas where they are subjected to natural and/or anthropogenic perturbations, and showed net increases in tree density and basal area. However, long-term studies are needed to understand the regeneration niche for individual species.

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