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Seed ecological and regeneration studies on keystone tree species of the evergreen and moist deciduous forest ecosystems

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CONTENTS

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ABSTRACT

Population structure, seed ecology and regeneration of dominant keystone tree species was assessed in seven plots established by Kerala Forest Research Institute in evergreen, moist deciduous and shola forests of Kerala. The study sites were evergreen forests at Muthikulam in Mannarkad Forest Division (10.5913 N; 76.3732 E), Pothumala in Nemmara Forest Division (10.4366 N; 76.6634 E), Vellanipacha in Peechi Wildlife Division (10.5838 N; 76.3316 E) and Vazhachal in Vazhachal Forest Division (10.1790 N; 76.3957 E). Moist deciduous forests includes Parambikulam in Parambikulam Wildlife Division (10.2442 N; 76.3866 E). Shola forests includes Mannavanshola (10.1080 N; 77.9500 E) and Vaguarrai (10.1862 N; 77.0953 E) in Eravikulam National Park.

Speicies studied from evergreen forests were *Cullenia exarillata*, *Mesua ferrea*, *Palaquium ellipticum* (Muthikulam & Pothumala), *Cynometra travancorica*, *Diospyros paniculata*, *Reinwardtiodendron anamalaiense* (Vellanipacha), *Dysoxylum malabaricum*, *Knema attenuata* (Vazhachal). *Cassia fistula*, *Catunaregam spinosa*, *Grewia tiliifolia* from moist deciduous forests in Parambikulam and *Gomphandra coriacea*, *Hydnocarpus alpina*, *Neolitsea scrobiculata*, *Syzygium densiflorum* from shola forests (Mannavanshola & Vaguarrai). Dominant among the species was *P. ellipticum* in Muthikkuluam and Pothumala, *R. anamalaiense* in Vellanipacha, *K. attenuata* in Vazhachal, *C. fistula* in Parambikkulum, *G. coriacea* in Vaguarrai and *H. alpina* in Mannavanshola.

Flowering and fruiting period is diferent in each species, *i.e*., *C. exarillata* (January-November), *P. ellipticum* and *K. attenuata* (December-July), *M. ferrea* (April- December), *C. travancorica* (September-April), *D. paniculata* (February-April), *R. anamalaiense* (March-November), *D. malabaricum* and *G. tilifolia* (February-June), *C. spinosa* (April-October), *S. densiflorum* (April-June), *G. coriacea* (December-March), *H. alpina* (February-July) and *N. scrobiculata* (May-August). Peak flowering of *C. fistula* is in March-April and fruits ripen during December.

Mode of seed dispersal in all the species is zoochory. The respective seed germination and seed moisture content of each species was as follows: *C. exarillata* (55 & 48.2 %), *P. ellipticum* (52 & 65.8 %), *M. ferrea* (70 & 55 %), *D.*

malabaricum (97 & 55 %) and *K. attenuata* (80 & 37 %). Storage physiology of most of the species is recalcitrant except *C. fistula* (orthodox), *C. spinosa*, *G. coriacea* and *G. tilifolia* (intermediate). Seed germination of all the species is hypogeal type of germination.

Regeneration of the species was enumerated under three girth classes as: ≤ 3cm (seedlings), 3.1 to 10 cm (saplings) and 10.0 to 30 cm (poles). Regeneration was good (seedlings > saplings > poles) for *C. exarillata* and *P. ellipticum* at Muthikkulum, *C. exarillata* at Pothumala, *Reinwardtiodendron anamalaiense* at Vellanipacha. On the other hand regeneration was poor for *M. ferrea* in Muthikkulum, *M. ferrea* and *P. ellipticum* in Pothumala, *D. malabaricum* and *K. attenuata* in Vazhachal, *C. travancorica* and *D. paniculata* in Vellanipacha, *C. spinosa*, *C. fistula* and *G. tiliifolia* in Parambikkulam, *H. alpina* and *N. scrobiculata* in Mannavanshola and *G. coriacea* and *S. densiflorum* in Vaguarrai. It presumes that poor regeneration will create gaps across different stages (seedlings-saplings-poles-adults) and the population will tend to decline in due course. The study points to need for augmentation of the dwindling species *in situ* to sustain ecosystems.

1. INTRODUCTION

Forests provide a variety of goods and services essential for human well-being (Risto Seppälä *et al*., 2009). At global level, forests have important bearing on the planet's climate while at the local level they provide a variety of ecosystem services and products. Tropical forests harbor a major share of terrestrial biodiversity and contain indispensable, self-maintaining repositories of genetic resources. Both abiotic and biotic factors may act singly or in combination to influence forest dynamics. Change in species composition may result in dramatic changes in the ecosystem structure and function. In many regions of the world, forests have become badly degraded and its protection implies regeneration and enrichment of species. So, it is important to enhance species composition, richness and density in order to maintain the population level and in this context it is very necessary to acquire relevant data on population dynamics for adaptive forest management. Forest ecosystem is a system self-perpetuating through many natural processes including succession, natural regeneration and homeostasis.

Replacement of older trees by younger ones in a forest is an important process in natural forest maturation. Studies on this aspect will contribute towards conservation and management of forest resources. Demographic assessment of regeneration is also useful to identify the constraints affecting natural regeneration. Natural regeneration is the "reproduction from self-sown seeds or by vegetative recovery from stumps, lignotubers, rhizomes or root suckers; often this takes place after the top of the plants have been killed by fire, cutting and browsing (Cremer, 1990). Natural regeneration is important as it addresses mainstream biodiversity concerns and it implies that plants established on a site are from parents that currently occupy the site (Ramesh *et al*., 2006; Reddy & Ugle, 2008). Hence it helps to preserve the diversity and dynamics of the population. Diversity is a key factor to sustain a 'healthy' ecosystem where natural regeneration plays a significant role. There are a lot of environmental, biological and physical barriers which control the process of natural regeneration of the species in a forest ecosystem. Poor seed viability, seed predation, lack of pollinators, seasonal variations and climatic change are noteworthy among them. Similarly, competition, canopy cover, fire, flood, wind, drought, etc. also affect successful establishment of individuals. Besides this, anthropogenic factors alter the function and composition of forests (Khan & Tripathi, 1989; Barik *et al*., 1996).

Degradation of tropical forests caused by climate or other changes, will lead to an irreversible loss in biodiversity. In some tropical areas, stressed by low soil moisture, mortality may increase in older forests and regeneration may decrease of species affected by it leading to competition with other species during the seedling stage. These changes may affect the continuity of plant life cycle stages. For example, pollen and seed development require minimum temperature and are sensitive to frost (Stern & Roche, 1974). Climate change may force variation in timing, duration and synchronization of phenological events in tropical forests and in turn influence seed production, recruitment and establishment of regeneration (Reich, 1995; Fitter & Fitter, 2002; Chapman *et al*., 2005). Some of the fauna also have important role in ecosystem processes and organization, such as pollination and seed dispersal. Extinction of such life forms has negative consequence on ecosystem resilience (Elmqvist *et al*., 2003). Climate change triggers multiple stress and disturbances that may influence structure and function of ecosystems. Generally seedlings are vulnerable to short-term droughts, saplings to the presence or absence of sunlight, and mature trees to the availability of growing-season soil water (McKenzie *et al*., 2009).

Often poor representation of saplings and poles in forests indicates anthropogenic constraints and that should be reduced to enhance adequate replacement of older trees (Reddy & Ugle, 2008). However, studies to understand the regeneration patterns of tropical trees are scanty. The Kerala Forest Research Institute (KFRI) has established permanent plots at different forest types in Kerala to evaluate the change in species composition and contribution. The present study was aimed to evaluate seed ecology and regeneration of major keystone tree species in those permanent plots. Keystone species plays a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community. An ecosystem may experience a dramatic shift if a keystone species is removed, even though that species was a small part of the ecosystem by measures of biomass or productivity. Hence, the study was undertaken.

2. MATERIALS AND METHODS

Population structure, seed ecology and regeneration of dominant keystone tree species were evaluated in the permanent plots. The plots were established by KFRI during 1998 - 2013 at different forest ecosystems in Kerala, *viz*., the evergreen forest at Muthikulam, Pothumala, Vellanimala and Vazhachal; moist deciduous forests at Parambikulam and shola forests at Mannavanshola and Vaguarrai (Fig. 1 & Table 1).

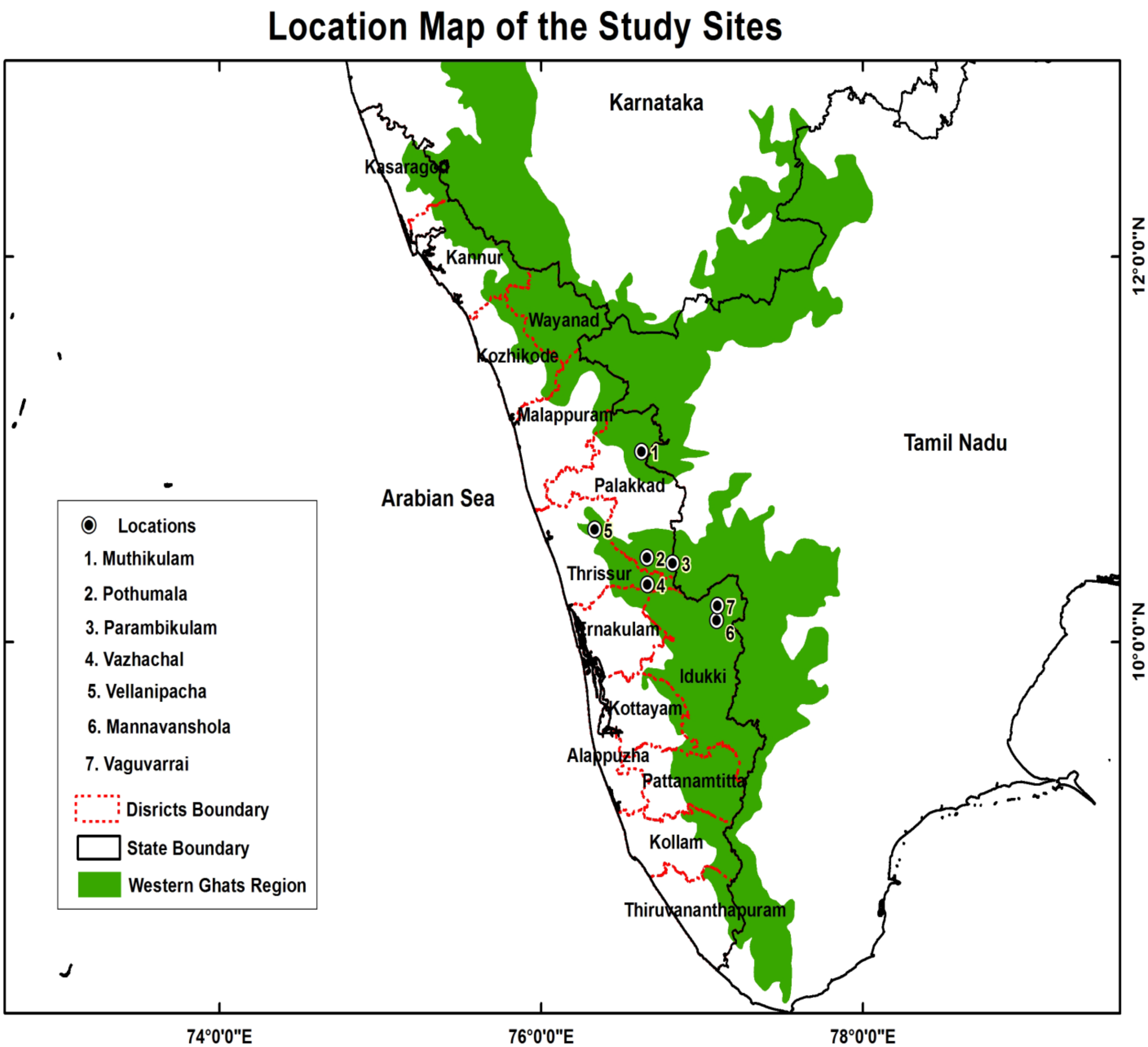


Fig. 1. Location map of permanent plots and study sites

Table 1. Location details of plots studied and year of establishment

Sl. No	Forest type	Locality	Forest Division	Year	Altitude (m)	Latitude (N)	Longitude (E)	Plot size (ha)
1	Evergreen	Muthikulam	Mannarkad	2012	774	10.5913	76.3732	1.0
2	Evergreen	Pothumala	Nemmara	1998	1096	10.4366	76.6634	1.0
3	Evergreen	Vellanipacha	Peechi WL	2000	524	10.5838	76.3316	0.5
4	Evergreen	Vazhachal	Vazhachal	2012	465	10.1790	76.3957	1.0
5	Moist Deciduous	Parambikulam	Parambikulam WL	2013	1120	10.2442	76.3866	1.0
6	Shola	Mannavanshola	Eravikulam NP	1998	1890	10.108	77.950	1.0
7	Shola	Vaguarrai	Eravikulam NP	2013	1926	10.1862	77.0953	1.0

Each plot was divided into 100 m^2 (10 x 10 m) sub-plots and demarcated. Regeneration was analyzed from the selected sub-plots (Fig. 2).

10	11	30	31	50	51	70	71	90	91
9	12	29	32	49	52	69	72	89	92
8	13	28	33	48	53	68	73	88	93
7	14	27	34	47	54	67	74	87	94
6	15	26	35	46	55	66	75	86	95
5	16	25	36	45	56	65	76	85	96
4	17	24	37	44	57	64	77	84	97
3	18	23	38	43	58	63	78	83	98
2	19	22	39	42	59	62	79	82	99
1	20	21	40	41	60	61	80	81	100

Fig. 2. Plot chart (shaded sub-plots were used for regeneration study)

The keystone species listed in Table 2 were selected for assessing structural status of population, seed ecology and regeneration status based on the phyto-sociological analysis done by earlier investigators (Chandrashekara *et al*, 1998; Chandrashekara & Muraleedharan, 2001). Height and girth at breast height (GBH) of the trees of selected species as well as associated species were measured from the plots. Individuals, which have greater than 30 cm GBH was considered as trees. The data were subjected to phyto-sociological analysis using the software 'InventNTFP' developed by KFRI (Sivaram *et al*., 2006). Calculated tree density and importance value index (IV) to evaluate structural status of mature trees. Regeneration was enumerated and categorized under different girth classes: ≤ 3 cm (seedlings), 3.1 to 10 cm (saplings) and 10.1 to 30 cm (poles) as per Menon (2010). Seedlings were counted for calculating their density (number of seedlings per ha). Saplings and poles were serially numbered, tagged and their girth and height were measured. The data were used for computing density and status.

Table 2. Details of selected mother trees in the study plots

Study sites	**Mother trees**	**Family**
Muthikkulam & Pothumala	*Cullenia exarillata* Robyns	Bombacaceae
	Mesua ferrea L.	Clusiaceae
	Palaquium ellipticum (Dalz.) Baill.	Sapotaceae
Vellanipacha	*Cynometra travancorica* Bedd.	Fabaceae
	Diospyros paniculata Dalz.	Ebenaceae
	Reinwardtiodendron anamalaiense (Bedd.) Mabb.	Meliaceae
Vazhachal	*Dysoxylum malabaricum* Bedd. ex Hiern	Meliaceae
	Knema attenuata (Hook. f. & Thoms.) Warb.	Myristicaceae
Parambikkulam	*Cassia fistula* L.	Fabaceae
	Catunaregam spinosa (Thunb.) Tirveng.	Rubiaceae
	Grewia tiliifolia Vahl	Tiliaceae
Vaguarrai	*Gomphandra coriacea* Wight	Icacinaceae
	Syzygium densiflorum Wall. ex Wight & Arn.	Myrtaceae
Mannavanshola	*Hydnocarpus alpina* Wight	Flacourtiaceae
	Neolitsea scrobiculata (Meisner) Gamble	Lauraceae

Keystone species is a species whose presence and role within an ecosystem has a disproportionate effect on other organisms within the system. It plays a critical role in maintaining the structure of an ecological community, affecting many other organisms in an ecosystem and helping to determine the types and numbers of various other species in the community. Removal of such species significantly alter the habitat around them and thus affect large numbers of other organisms (Mills *et al*., 1993).

Tree density is the measure of stocking in a stand based on number of trees per unit area (number of trees per ha). Importance Value Index (IVI) is also a measure of how the dominant species is in the area (Misra, 1968). It is the summation of relative density, relative frequency and relative dominance/basal area. Relative frequency is the percentage of inventory points occupied by the species as a percent of the occurrence of all species. Relative density is the number of individuals per area as a percent of the number of individuals of all species. Relative basal area is the total basal area of the species as a percent of the total basal area of all species. Basal area is the sum of the cross sectional area of all trees of the species measured at GBH (girth at breast height).

3. RESULTS AND DISCUSSION

Enumeration was carried out in the permanent plots of different forest types in Kerala *viz*., Evergreen, Moist Deciduous and Shola forests. Population structure, reproductive biology, seed ecology and regeneration of the selected keystone species in the study sites were analyzed and presented below. Mode of seed dispersal, storage physiology and germination patterns were assessed for each species. The tree density (number of trees per ha) and IVI (Importance Value Index) of the selected species in the study areas provided in the Table 3. Results of regeneration studies of the species carried out are given in Table 4.

Table 3. Tree density (individuals/ha) and IVI values of selected mother trees in the study plots

Study sites & forest types	Mother trees	Tree density	IVI
Muthikkulam (Evergreen forest)	*Cullenia exarillata*	89	49.74
	Mesua ferrea	34	12.01
	Palaquium ellipticum	369	42.91
Pothumala (Evergreen forest)	*Cullenia exarillata*	86	29.01
	Mesua ferrea	63	23.33
	Palaquium ellipticum	168	58.82
Vellanipacha (Evergreen forest)	*Cynometra travancorica*	92	15.19
	Diospyros paniculata	104	22.15
	Reinwardtiodendron anamalaiense	140	28.42
Vazhachal (Evergreen forest)	*Dysoxylum malabaricum*	6	1.98
	Knema attenuata	135	46.37
Parambikkulam (Moist deciduous forest)	*Cassia fistula*	43	31.38
	Catunaregam spinosa	21	14.28
	Grewia tiliifolia	18	31.66
Vaguarrai (Shola forest)	*Gomphandra coriacea*	63	22.22
	Syzygium densiflorum	29	27.50
Mannavanshola (Shola forest)	*Hydnocarpus pentandra*	136	33.96
	Neolitsea scrobiculata	17	4.41

Table 4. Regeneration of selected trees in the study area

Study sites & forest types	Species	Regeneration(ha^{-1})			
		Seedling	Sapling	Pole	Total
Muthikkulam (Evergreen forest)	*Cullenia exarillata*	848	105	64	1017
	Palaquium ellipticum	1712	556	172	2440
	Mesua ferrea	32	0	4	36
Pothumala (Evergreen forest)	*Palaquium ellipticum*	920	8	8	936
	Cullenia exarillata	76	28	16	120
	Mesua ferrea	6	4	0	10
Vellanipacha (Evergreen forest)	*Reinwardtiodendron anamalaiense*	477	154	31	662
	Diospyros paniculata	208	261	23	492
	Cynometra travancorica	231	231	39	501
Vazhachal (Evergreen forest)	*Knema attenuata*	228	4	0	232
	Dysoxylum malabaricum	4	0	0	4
Parambikkulam (Moist deciduous forest)	*Grewia tiliifolia*	16	4	0	20
	Cassia fistula	52	12	0	64
	Catunaregam spinosa	16	32	8	56
Vaguarrai (Shola forest)	*Syzygium densiflorum*	10	50	0	60
	Gomphandra coriacea	0	100	0	100
Mannavanshola (Shola forest)	*Hydnocarpus pentandra*	16	4	0	20
	Neolitsea scrobiculata	16	32	8	56

3.1. Study sites in evergreen forests

3.1.1. Population structure

Major keystone species identified from the plots at Muthikkuluam and Pothumala were *Cullenia exarillata*, *Mesua ferrea* and *Palaquium ellipticum*. Two of them *viz*., *C. exarillata* and *P. ellipticum* are endemic to Western Ghats. Many arboreal mammals including primates and bats feed on the fruits of these species. *Cullenia exarillata* is harboured by many epiphytes such as *Eria*, *Peperomia* and *Bulbophyllum* (Devy, 2006). This tree acts as a hot bed of activity when in flower and functions as a keystone resource for several species of arboreal mammals, including the endangered primate Lion tailed macaque and Nilgiri langur. Relationship with other flora and fauna makes these species valuable in functional and ecological point of view. Tree density (stems ha^{-1}) was higher for *Palaquium ellipticum* in Muthikkuluam (369) and Pothumala (168) experimental sites followed by *C. exarillata* (89 and 86) and *M. ferrea* (34 and 63). *Cynometra travancorica*, *Diospyros paniculata* and *Reinwardtiodendron anamalaiense* were the dominant species in the plot at Vellanipacha. *Diospyros paniculata* is an endemic species to peninsular India, *C. travancorica* and *R. anamalaiense* are endemic to southern Western Ghats. Moreover, *C. travancorica* is an endangered species listed in the IUCN red data book (IUCN, 2010). It has antibacterial activity against Gram negative and Gram positive bacteria (John *et al*., 2012). *Reinwardtiodendron anamalaiense* was the most dominant species in terms of density as well as IVI followed by *D. paniculata* and *C. travancorica*. *Dysoxylum malabaricum* and *Knema attenuata* were the major species recorded from the plot at Vazhachal, which are endemic to Western Ghats. *Knema attenuata* was dominant among the species.

3.1.2. Reproductive biology and seed ecology

Cullenia exarillata is cauliflorous, producing flowers and fruits on older branches observed as an adaptation for pollination. Flowering and fruiting is during January to November. Figure 3 represents flowers, fruits and regeneration of *C. exarillata*. Seed dispersal is zoochory, i.e., seeds of the species is dispersed by animals. Fruits of *C. exarillata* is the favored food of Lion-tailed Macaque. Average germination of fresh seeds under laboratory condition was 55 per cent with a hypogeal germination. Germination commenced from 44 days after sowing (DAS) and culminated at 141 days. An earlier report showed 80 per cent germination when seeds treated with Dithane-45 for 5 minutes (Gideon *et al*., 2015). Moisture content of fresh seed was 48.2 per cent and it showed recalcitrant nature.

Fig. 3. Flowers (a), fruits (b) and regeneration (c) of *Cullenia exarillata*

Flowering of *P. ellipticum* is from December-March and fruiting March-July. Figure 4 represents flowers, seed germination and regeneration of the species. Fruit is a one/two-seeded berry. Due to the pleasant smell, flowers get frequently visited by bees, small insects and flies. Malabar giant squirrels are the major predators of the species. Mainly the seed dispersal is through Malabar giant squirrels and bats. Fresh seeds recorded 52 per cent germination under laboratory condition with epigeal type of germination. Seeds commenced germination 17 DAS and culminated in 50 days. Seed moisture content was 65.8 per cent. Seeds are under the recalcitrant group.

Fig. 4. Flowers (a), seed germination (b) and regeneration (c) of *Palaquium ellipticum*

Mesua ferrea flowers during April-May. Fruits are ovoid with 1-4 pyriform dark brown coloured seeds. Figure 5 represents flowers, fruits and regeneration of the species. Common pollinators are *Thrips* sp. (Orwa *et al*., 2009). Opening of flowers during 3-4 am and closing around sunset. Fruits mature during October-December. Fruit is a capsule, thinly woody, usually dehiscing with 2-4 vales before falling and its seed dispersal is zoochory similar to other two species. Seeds of the species are under the recalcitrant group. Seed germination was 70 per cent under laboratory condition with hypogeal type of germination. Germination commenced 15 DAS and ended at 90 DAS. Seed predation may be one of the reasons for reduce the rate of natural regeneration.

Fig. 5. Flowers (a), fruits (b) and regeneration (c) of *Mesua ferrea*

Flowering and fruiting of *Cynometra travancorica* occur during September-April. Fruit is an indehiscent one-seeded pod. Mode of seed dispersal is by birds. Flowers of *D. paniculata* are yellowish-white and attract bees, birds, etc. Flowering and fruiting of the species was during February-April. Fruit dispersal is through animals like bats, squirrels and birds. Flowers of *R. anamalaiense* are attractive and yellowish white in colour. Flowering and fruiting of the species are observed during March-November. Its fruit is 1-2 seeded berry embedded in a pulpy aril and its dispersal is by birds.

Flowering and fruiting of *D. malabaricum* was during February-June. Fruit is a 3-4 seeded capsule. Mode of pollination is entomophily, and seeds are predated by Malabar grey hornbill and other birds like imperial pigeons and wood pigeons (Ganesh & Davidar, 2001). Hence, it is zoochory. Seed weight is about 120-190 seeds/kg. Fresh seeds have 55-60 % moisture content. Their storage physiology is recalcitrant and quickly lost viability. Fresh de-coated seeds had 96.63 ± 0.06 per cent germination under laboratory condition with epigeal type of germination; whereas, seeds with seed coat provided poor germination (16.67 ± 2.35 %). Similarly, the de-coated seeds commenced germination from 14 DAS and it culminated at 45 DAS and the seeds with seed coat initiated germination only from 34 DAS and continued up to 113 DAS (Pillai & Pandalai, 2015). An earlier report mentioned that germination of fresh de-coated seeds starts with 13 DAS (Chacko, 2009).

Knema attenuata flowers during December-March and November-December. Fruiting is during December-July. Fruit is a one-seeded capsule with aril. Hornbill, Primates, squirrels, rodent, etc. consume its fruits (Ramachandran & Joseph, 2001; Kitamura & Poonswad, 2013). Therefore, the mode of seed dispersal is zoochory. Mature seeds with moisture content of 37 % exhibited above 80 % germination under laboratory condition. It is intolerant to desiccation below 25 % moisture content. Complete loss in viability resulted when seed moisture was reduced to 18 %; hence, it comes under recalcitrant group.

3.1.3. Regeneration

Regeneration status of the selected species in each site is depicted in Figures 6 to 16. Figures 6-8 showed the seedlings of *C. exarillata* and *P. ellipticum* in the plot of Muthikulam were more than saplings and saplings more than poles, i.e., seedlings > saplings > poles. Among them, *P. ellipticum* showed better performance. The trend revealed a good regeneration status and in future population of the species maintained well in that area. However, in the case of *M. ferrea*, only seedlings and poles were recorded from the plot with a trend of very poor status (seedlings > poles).

With respect to the plot at Pothumala (Figs. 9-11), seedlings of *C. exarillata* are higher than that of other species and display a stable regeneration status. Though the seedlings of *P. ellipticum* were higher in number, their saplings and poles were negligible. However, in the case of *M. ferrea*, only seedlings and saplings were reported that too in very low density. Low density of the seedlings is due to post emergence mortality caused by *Fusarium* sp. causes severe root rot. In this plot, regeneration status was better only for *C. exarillata*. In an earlier study by Chandrashekara *et al*. (1998) reported that the contribution of these species to the total IVI of sapling population is only about 10 %. Chandrashekara and Jayaraman (2002) reported that regeneration of primary species in the plot was poor as indicated by density in the seedling phase, even in the plot which is not being managed since about 5 years. Such plots are likely to transform into ‘open moist forests’ (Pillai, 1919).

Figures 12-14 represent regeneration status of the plot at Vellanipacha, which showed that regeneration of *R. anamalaiense* was very good when compared to other species. Saplings of *D. paniculata* were more among the three life forms of regeneration. Seedlings and saplings of the *C. travancorica* were more than that of poles. Though the regeneration of *C. travancorica* in study site had all the three life stages, it did not follow the general hierarchy (Seedlings > saplings > poles) since the number of seedlings and saplings were equal; hence, regeneration is not satisfactory (Khumbongmayum *et al*., 2006). More or less similar result was found in *D. paniculata*, where saplings were more than that of other categories. However, with respect to *R. anamalaiense*, it follows a stable hierarchy of different life stages.

Regeneration status of *D. malabaricum* and *K. attenuata* tends to be very poor. Regeneration of *K. attenuata* was represented only by seedlings and saplings; however, the number of saplings were negligible (Fig. 15). With respect to the regeneration of *D. malabaricum*, only seedlings were observed in the study site (Fig. 16). Absence of saplings and poles of *D. malabaricum* may be due to collar rot caused by the fungus, *Sclerotium roflsii*. Since the plot was in an evergreen forest with closed canopy, where the annual rainfall is high favours optimum fungal incidence. The study indicated that regeneration status of both the species was quite poor in the plot.

Fig. 6. *Cullenia exarillata*

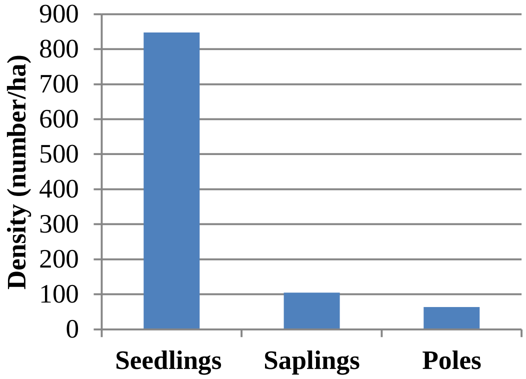


Fig. 7. *Palaquium ellipticum*

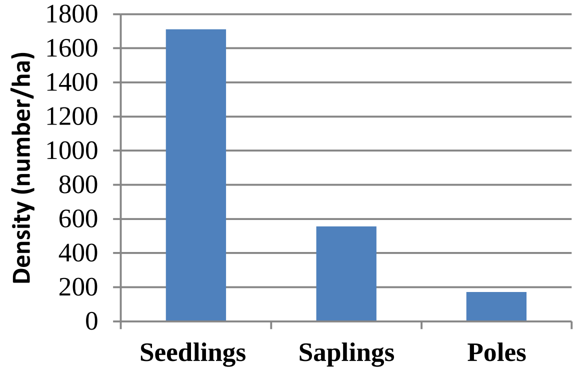
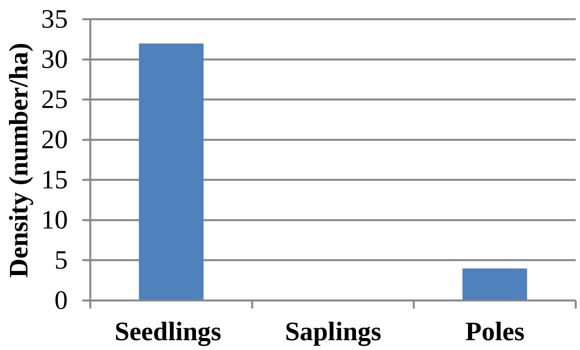


Fig. 8. *Mesua ferrea*



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Figs. 6-8. Regeneration status of *C. exarillata, P. elliptium and M. ferrea* at Muthikkulum.

Fig. 9. *Cullenia exarillata*

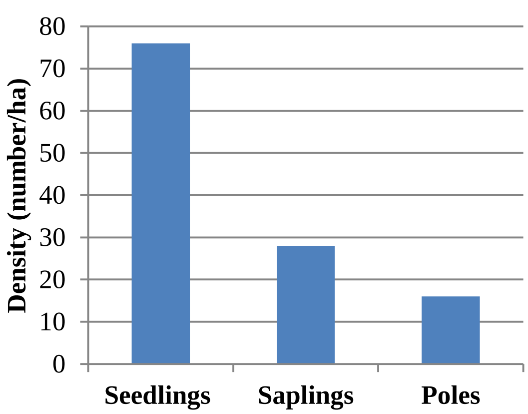


Fig. 10. *Palaquium ellipticum*

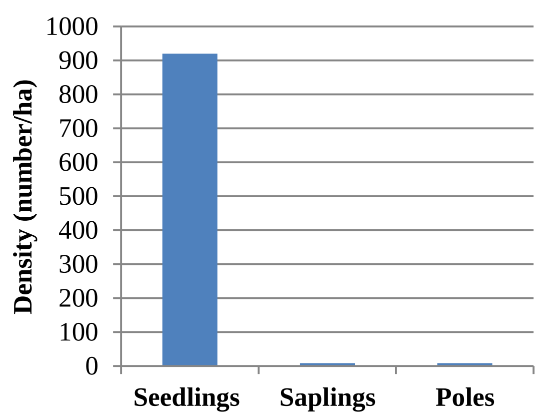
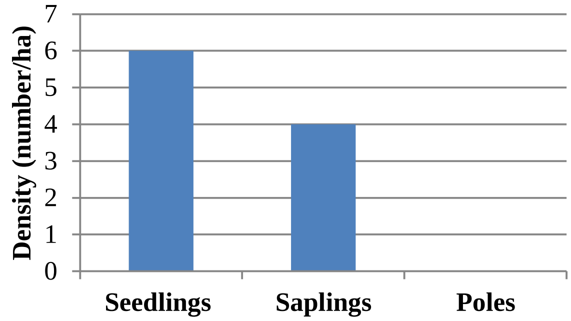


Fig. 11. *Mesua ferrea*



Figs. 9-11. Regeneration status of *C. exarillata*, *P. elliptium and M. ferrea* at Pothumala

Fig. 12. *R. anamalaiense*

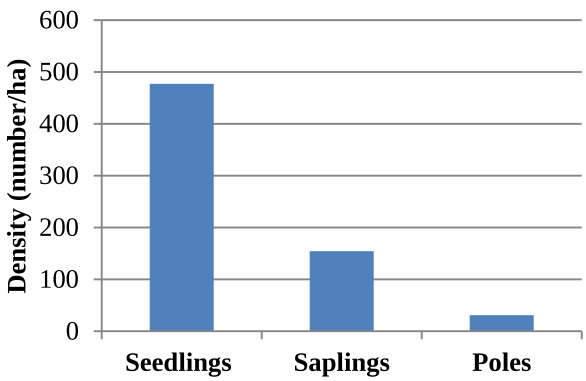


Fig. 13. *Diospyros paniculata*

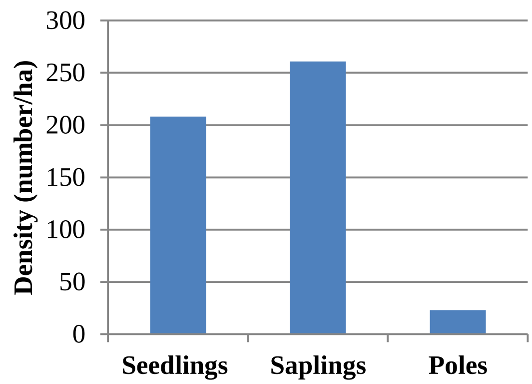
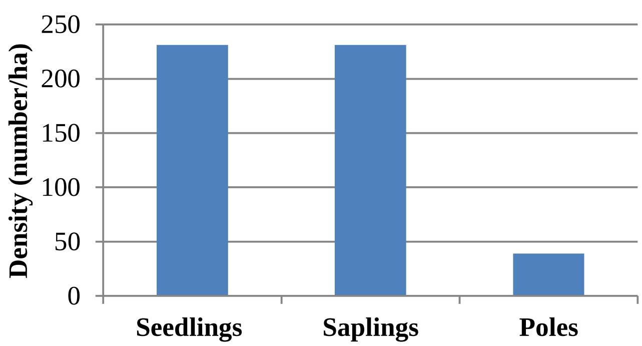
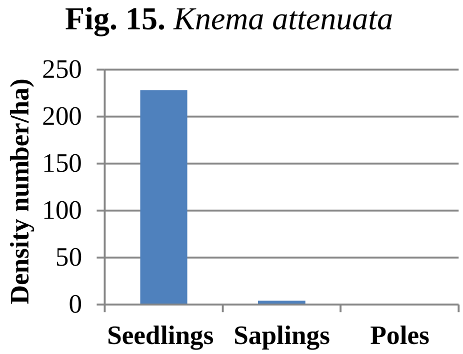
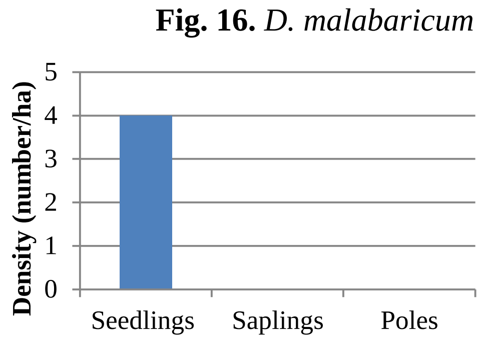


Fig. 14. *Cynometra travancorica*



Figs. 12-14. Regeneration status of dominant tree species at Vellanipacha





Figs. 15-16. Regeneration status of *K. attenuata* and *D. malabaricum* at Vazhachal

3.2. Study sites in moist deciduous forests

3.2.1. Population structure

Cassia fistula, *Catunaregam spinosa* and *Grewia tiliifolia* were the dominant species in the plots at Parambikkulum. Tree density was more in *C. fistula* (43 stems ha^{-1}) followed by *C. spinosa* (21 stems ha^{-1}) and *G. tiliifolia* (18 stems ha^{-1}). *Catunaregam spinosa* is used as a traditional medicine and can be well exploited for various pharmacognostical studies (Senthamarai *et al*., 2011).

3.2.2. Reproductive biology and seed ecology

In general, flowering and fruiting of *C. fistula* varied according to geographical location and climate. However, peak period of flowering is March-April. It exhibits flower initiation in response to increasing length of photoperiod. Flowers are yellow colored, attractive to bees and butterflies. Fruit is a long cylindrical pod, which ripen during December and continue to March-April. Seed weight is in the range 5,650-7,000 seeds/kg. Storage physiology of the seed is orthodox. Seeds are predated by squirrels and rats; hence, seed dispersal is zoochory. Seeds are infested by insect *viz*., *Piesmopoda obliquifasciata*, *Trachylepidia fructicasseilla* and *Oxyrhachis rufescens* (Khan & Zaki, 2012). Seeds can be stored for long duration under cold condition. Pre-treatment is required for better seed germination. Soak the seeds in boiled water for 5 minutes and then cold water for 24 hr. Acid (Con. H_2SO_4) scarification for about 6 minutes is the best treatment for enhancing seed germination. Germination is epigeal.

Flowering and fruiting of *C. spinosa* occurs during April - October. Fruit is an obovoid berry with many seeds embedded in pulp. Seed dispersal is zoochory. Storage physiology of the seeds are intermediate type. Per-treatments are not required for seed germination. Flowering of *Grewia tilifolia*, was observed in February and seeding during May. Fruit is a two-seeded drupe. Fruits ripen during March-June and it attained reddish-purple color when mature. The fruits are edible and largely consumed by birds, squirrels, etc. Therefore, seed dispersal is zoochory. Several Lepidoptera are also found to feed on the species. Seed (de-pulped) weight is about 16,000-19,400 seeds/kg. Insect infestation is very low; however, fungal infestation is reported by Chacko *et al*. (2001). Seed do not retain viability for long, but can be stored at least for 4 months (Chacko *et al*., 2001). Their storage behavior is intermediate. Germination is epigeal. Pre-sowing treatment is not necessary, since untreated seeds have better germination than those treated in cold/hot water (Chacko *et al*., 2001).

3.2.3. Regeneration

Cassia fistula and *G. tiliifolia* had only seedling and sapling groups among the life forms of regeneration (Figs. 17 and 18). In contrast to this, all the three stages of regeneration were observed in *C. spinosa*, where saplings were higher than that of other stages (Fig. 19). Results indicated that regeneration in the study site was poor.

Fig. 17. *Cassia fistula*

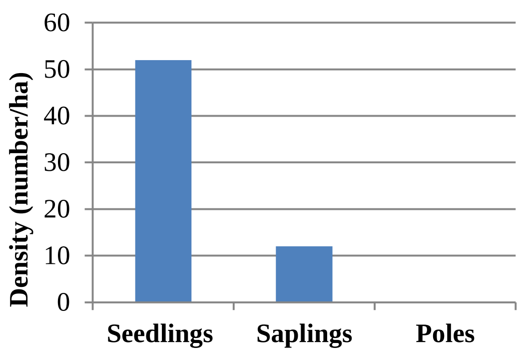


Fig. 18. *Grewia tiliifolia*

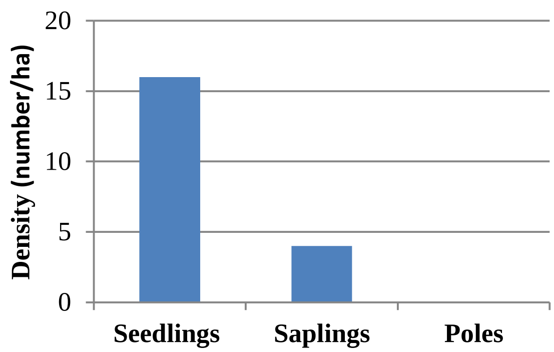
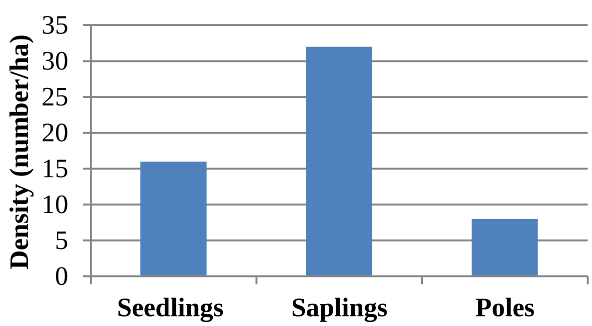


Fig. 19. *Catunaregam spinosa*



Figs.17-19. Regeneration status of *C. fistula*, *G. tiliifolia* and *C. spinosa* at Parambikkulam

3.3. Study sites in shola forests

3.3.1. Population structure

Dominant trees in the permanent plot at Vaguarrai were *Gomphandra coriacea* and *Syzygium densiflorum*. Among them *S. densiflorum* is an endemic species found in southern Western Ghats and categorized as a vulnerable species in the IUCN red list. That species has been traditionally used by local tribes of the Nilgiris for the treatment of diabetes. Tree density was higher in *G. coriacea* (63 stems ha^{-1}) than *S. densiflorum* (29 stems ha^{-1}). Similarly, *Hydnocarpus alpina* and *Neolitsea scrobiculata* were the major trees recorded at Mannavanshola. Among them *H. alpina* was the dominant species (136 stems ha^{-1}). *Neolitsea scrobiculata* is endemic to Western Ghats.

3.3.2. Reproductive biology and seed ecology

Flowering and fruiting period of *S. densiflorum* is during April-June. Fruit is a dark purple coloured berry. They are recalcitrant in nature. Seed dispersal is zoochory, i.e., dispersal of seeds by birds and other arboreal animals. Pre-treatment is not required; however, de-pulping helps to enhance seed germination. *Gomphandra coriacea* is a small tree growing in shola forests. Flowering and fruiting of *G. coriacea* is during December-March. Seeds are intermediate type and their mode of dispersal is by birds and other arboreal animals.

Flowering and fruiting of *H. alpina* reported in February-July. Fruit is a many seeded berry. Seed dispersal of the species is zoochory. Seeds are under the category of recalcitrant. No pre-treatment is required for seed germination. Flowering and fruiting of *N. scrobiculata* is during May-August. Fruit is a drupe with a basal rim of perianth tube. Seed dispersal is zoochory as well as hydrochory. Storage physiology of the seed is intermediate. Seed germination is not a problem for the species.

3.3.3. Regeneration

Figures 20 and 21 depict regeneration status of the species in the plot of Vaguarrai. Two stages of regeneration (seedlings and saplings) were reported for *S. densiflorum*, among them saplings were more than seedlings (Fig. 20). In the case of *G. coriacea*, only saplings were observed from the plot (Fig. 21). The result indicated that regeneration of the species in the plot was very poor and a large gap will be resulted between these stages in due course of time.

Fig. 20. *Syzygium densiflorum*

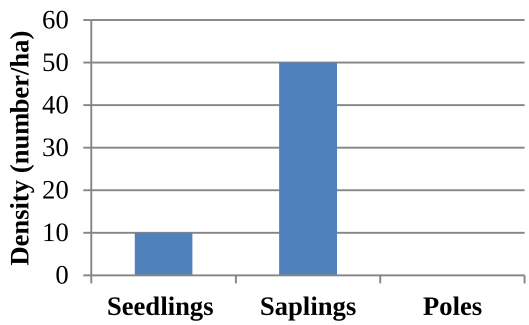
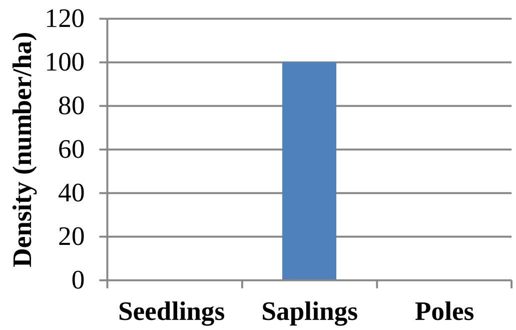


Fig. 21. *Gomphandra coriacea*



Figs. 20-21. Regeneration status of *Syzygium densiflorum* and *Gomphandra coriacea* at Vaguarrai

With respect to the regeneration in the plot of Mannavanshola, only seedling and sapling stages were reported for *H. alpina* with limited individuals and poles were totally absent (Fig. 22). This missing stages indicate the unsatisfactory regeneration status for the species. Though all the three stages of regeneration were encountered of *N. scrobiculata*, sapling category was more in number (Fig. 23). However, regeneration status was not satisfactory in the study site.

Fig. 22. *Hydnocarpus alpina*

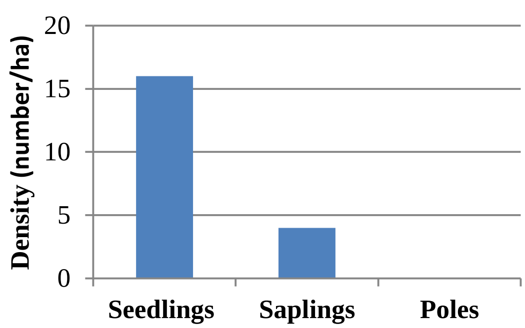
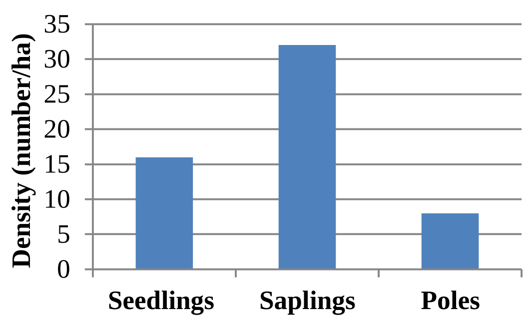


Fig. 23. *Neolitsea scrobiculata*



Figs. 22-23. Regeneration status of *H. alpina* and *N. scrobiculata* at Mannavanshola

Absence of young trees in a forest indicates poor regeneration (Saxena & Singh, 1984; Reddy & Ugle, 2008). Earlier studies reported that open canopy favours establishment of seedlings by increasing incidence of solar radiation on forest floor and consequent increase in surface temperature, and reduced competition from the canopy layer (Khan *et al*., 1987; Tripathi & Khan, 1992; Srinivas, 1992). Light penetration to the ground is a major factor for seed germination and establishment of regeneration (Ashton, 1988; Manokaran & LaFrankie, 1990). Scarcity of saplings infers impact of forest fire, grazing, and exotic weeds on natural regeneration (Reddy & Ugle, 2008). In ecological point of view, this state is not good, regenerating level tends to be very low and sustenance of the species in the stand may be a problem. Reason for poor regeneration may be pre- and post- emergence mortality of seedlings due to microbial intervention. The dense canopy, which prevents light to reach forest floor, may be another reason for poor regeneration, leading to increase in moisture content which is more congenial for fungal growth. Sometimes, continuous drought make problem for the survival of seedlings and saplings, thus badly affecting regeneration.

As it is well known that regeneration status of a species is preliminary based on population size of seedlings and saplings (Bhuyan *et al*., 2003; Pokhriyal *et al*., 2010), and according to Khumbongmayum *et al*. (2006), regeneration is said to be good if the proportion is seedlings > saplings > adults; fair if seedlings ≤ saplings > adults; poor if the species survives only in sapling stage (saplings may be ≤ adults). Our results corroborates with that of Khumbongmayum *et al*. (2006).

4. CONCLUSIONS

Assessment of the regeneration of dominant keystone species in the permanent plots established by the Kerala Forest Research Institute in different forest types of Kerala concluded that regeneration status was good (seedlings > saplings > poles) for *Cullenia exarillata* at Muthikkulum and Pothumala. Similar status was observed at Muthikkulum for *Palaquium ellipticum* and *Reinwardtiodendron anamalaiense* at Vellanipacha. However, regeneration status of *Mesua ferrea* at Muthikkulum and Pothumala was poor. So as is the case of *P. ellipticum* at Pothumala; *Cassia fistula*, *Grewia tiliifolia* and *Catunaregam spinosa* at Parambikkulam; *Cynometra travancorica* and *Diospyros paniculata* at Vellanipacha; *Knema attenuata* and *Dysoxylum malabaricum* at Vazhachal; *Syzygium densiflorum* and *Gomphandra coriacea* at Vaguarrai; and *Hydnocarpus alpina* and *Neolitsea scrobiculata* at Mannavanshola. Absence of young trees (saplings) in plots indicates poor regeneration. The study presumes that poor regeneration will generate gap across different stages (seedlings-saplings-poles-adults) and the population will tend to decline in due course, and this will influence the structure and composition of the ecosystems. Hence, some necessary actions should be taken against the paucity through augmentation of the species by restoration/assisted natural regeneration.

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