Phenological behaviour of selected tree species in tropical forests at Kodayar in the Western Ghats, Tamil Nadu, India

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Vegetative and reproductive phenology of 42 tree species of tropical forests at Kodayar in the Western Ghats, Tamil Nadu, India was monitored through fortnightly visits for two years. A considerable variation was found in leaf flushing, leaf fall, flowering and fruiting behaviour that could be partly attributed to abiotic factors. Peak activity of leaf fall and leaf emergence that occurred in the early dry period, could be to take full advantage of the first rainy season for vegetative growth and reproduction. Peak flowering activity coincided with leaf fall/leaf flushing, possibly to attract pollinators. The activity of fruit ripening and fruit fall was at its peak in the first rainy season in order to utilize the available soil moisture for seed germination and seedling establishment. Phenological behaviour displayed by the trees is an adaptation to the surrounding abiotic and biotic environment.

DURING the last few decades, forests at Kodayar, Western Ghats, Tamil Nadu were subjected to unscientific exploitation, particularly for agriculture, construction of hydroelectric projects, raising monoculture plantations, etc. Sustainable management of natural tropical forests is not possible without a better holistic understanding of their ecological functioning. As part of an integrated research project, a general hypothesis was framed to test the influence of anthropogenic perturbations on ecosystem structure and functional processes in tropical forests at Kodayar[1]. Plant phenological studies are fundamental to understand the forest as a resource base for other dependent populations or communities. Tropical plant communities display conspicuous seasonal pattern in vegetative and reproductive phenologies at both community and species levels[2–4]. Seasonality in phenological events has been reported to influence faunal diversity. More recently, efforts have been made to discern the importance of general community patterns in leafing, flowering and fruiting for many species of which particular forest types are composed[2,5]. Information on phenological patterns of natural forest vegetation in tropical forests of the Western Ghats is limited[6–10]. Therefore, the present study aims to monitor and describe the vegetative and reproductive phenological events of dominant tree species occurring in the forest ecosystems and to relate the role of biotic and abiotic factors in determining these events.

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The study area at Kodayar (village), located 400 km south of Madurai (77°15′E, 8°29′N) is at an elevation of 250–650 m in Kanyakumari District, Tamil Nadu, South India. The mean annual rainfall recorded in the study area was 2338 mm, of which 81% was received from June to November (Figure 1). Average monthly maximum and minimum temperatures were 30 and 26°C in summer and 28 and 24°C in winter, respectively.

The moist deciduous trees that dominated in the study area are *Terminalia paniculata* Roth, *Careya arborea* Roxb., *Buchanania lanzan* Spr., *Emblica officinalis* Gartner, *Dillenia pentagyna* Roxb., *Aporosa lindleyana* Baill., *Pterocarpus marsupium* Roxb., and *Terminalia arjuna* W. and A (Table 1). The herbaceous community is mostly dominated by *Themeda cymbaria* Hack., *Themeda* sp., *Globba orixensis* Roxb., *Imperata cylindrica* Dur. and Sch., and *Thespesia lampas* Dalz. Dicotyledonous shrub species are *Helicteres isora* L. and *Chromolaena odorata* K&R. The evergreen species that dominated in the study area 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 is dominated by *Psychotria nigra* L., *Psychotria* sp., *Calamus* sp., *Memecylon* sp. and *Isonandra lanceolata* W. The herbaceous species composition is dominated by *Oplismenus compositus* Beauv. and *Panicum* sp. under open canopies. The two study sites are located within a range of 10 km, but the evergreen site is on the lower slopes along the Kodayar river surrounded by hillocks. Therefore, in this site the stand density (dominated by evergreen trees) and humidity are high with considerable variation in the microclimate. Unfortunately, no climatic data were available for this site. On the contrary, the deciduous site (dominated by deciduous trees) is near human habitation and an open lowland subjected to biotic stresses, and wild annual ground fires. It is believed that these deciduous forest fragments at Kodayar are possibly the transformations of the evergreen forests, which were subjected to various biotic and abiotic stresses in the past.

Five individuals of each of the 42 selected dominant tree species of the same (age) girth class (± 5 cm DBH) were

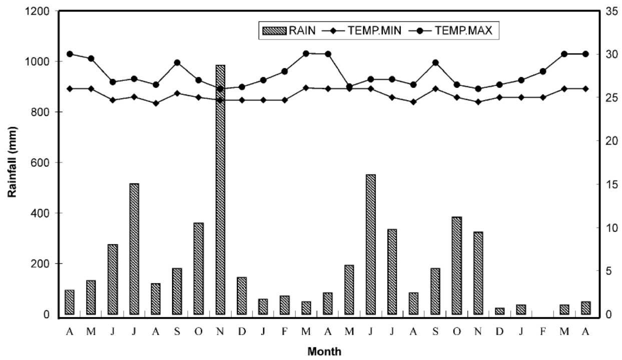

Figure 1. Ombrothermic diagram for the study area, mean monthly maximum and minimum temperature (°C) and rainfall (mm).

marked with a metal tag. Each individual was observed once every a fortnight for two years to record phenological events such as (i) production of young leaves (YL), (ii) maturation of leaves (ML), (iii) abscission of leaves (AL), (iv) production of flowers (YF), (v) maturation of flowers (MF), (vi) abscission of flowers (AF), (vii) production of young fruits (YFR), (viii) maturation of fruits (MFR), and (ix) ripening of fruits (RFR). During fortnightly visits, all marked individuals were qualitatively characterized and the phenostage of a species was determined by considering their status. For classifying the species into different dispersal modes, first-hand observation was made on dispersal agents for as many species as possible. Where direct observations were not possible, the mode of dispersal was inferred from fruit morphology. Species with fleshy content were considered animal-dispersed, even if we could not detect their seeds in animal droppings. Those with winged seeds or fruits were considered wind-dispersed, while those which did not possess any of these characters, were classified as explosive or others[10]. Species were classified on the basis of flowering behaviour following Newstrom *et al.*[11]. Spearman's rank correlation coefficients between climatic factors (rainfall and temperature) and the frequency of leafing, flowering and fruiting were calculated. Spearman's rank correlation coefficients were also computed between rainfall and the number of species in each dispersal guild. In order to know the extent to which fruiting phenologies of species within a guild overlap, Hulbert's general overlap measure[12] was calculated[10,13].

Seasonal peaks for leaf flush and leaf fall are quite common in tropical rainforest, pronounced by dry periods[14]. In the present study most of the tree species observed had their leaf fall during the early dry season (December–January), but in some species it continued in later months also (Figure 2). In other words, leaves emerge and mature during the period with minimal rainfall, high temperature and increasing day length. Leaf fall occurs when the temperature begins to decrease and day length is short. Similar results were reported by Shukla and Ramakrishnan[15], and Bhat[7,8] in tropical forests of India, and elsewhere by others[16,17]. The dry season leaf abscission is attributed to avoid water stress and/or it may also be a mechanism of maintaining shoot turgidity[18,19], However, leaf abscission is a complex process. Many phenomena may alter the timing of leaf abscission, but water availability may not be a critical factor. For example, Bernhard-Reversat *et al.*[20] found strong correlation between incident radiation and leaf fall, and no correlation with precipitation. The species-specific leaf-shedding phenology affecting the shift in peak leaf fall has been reported by others[21]. The peak activity of leaf emergence in many tree species coincided with dry season (February–March). Leaf flushing and new leaf production were also observed after the dry season in few tree species. The peak activity of leaf maturation occurred during March–May in many species. In general, leaf emergence of most of the species was seasonal and it occurred once in a year, whereas in *D. latifolia* and *P. marsupium*, the activity of leaf emergence was observed twice a year. Many deciduous tree species were leafless in February, whereas few of them were leafless in March also. However, evergreen species showed no concentrated leaf fall during the study period. Peak activity of leaf emergence in the dry season observed in the present study is in agreement with other observations[2,7–9,15]. In the present study, rainfall and temperature showed no significant correlation with leafing (Table 2), while one-month lag showed significant correlation with rainfall ($r_s = 0.769$; $P < 0.05$). The pre-rain leaf flushing was attributed to the triggering effect of the raising temperature, and leaf flushing prior to the rainy season may also be a trigger to avoid herbivory[9]. This may also be applicable to the results obtained in present study, but such a correlation was not observed in the tropical forests of Costa Rica[16] and Malaysia[22]. Nevertheless, the dry season leaf flushing permits renovation of the canopy before the monsoon rain arrives, such that the plants are able to take full advantage of the short rainy season for their growth and production. Further, at community level, leaf flushing continued several months ensuring continued availability of new photosynthetically active tissue[18]. The ability of flushing trees to overcome soil moisture stress during the dry season is not clear. The possible explanation to this could be that the trees may have deep tap roots that reach groundwater. Another possibility could be that, in the absence of transpiration during leaf less-phase, trees are able to store some amount of water in their conductive tissues for subsequent use during the early leaf-flushing phase[18,19].

The peak activity of flower bud inception coincided with that of leaf fall and leaf flush (January–April; Figure 2). How

Table 1. Vegetational characteristics of the study area in tropical forests at Kodayar, Western Ghats of Tamil Nadu

Criterion	Deciduous forest	Evergreen forest
Number of families (trees)	15	22
Number of species (tree species/ha)	22	37
Tree density (No./ha)	352	748
Species type		
Evergreen species	3	37
Deciduous species	19	0
Dispersal guilds		
Animal	8	13
Wind	5	3
Explosive	1	–
Others	1	3
Level of disturbance	Very high (fire)	Little
Dominant species	*Terminalia paniculata* *Buchanania lanzan* *Pterocarpus marsupium* *Careya arborea* *Dillenia pentagyna* *Emblica officinalis* *Aporosa lindleyana* *Holarrhena pubescens*	*Hopea parviflora* *Syzygium laetum* *Vateria indica* *Ixora brachiata* *Xanthophyllum flavescens* *Carallia brachiata*

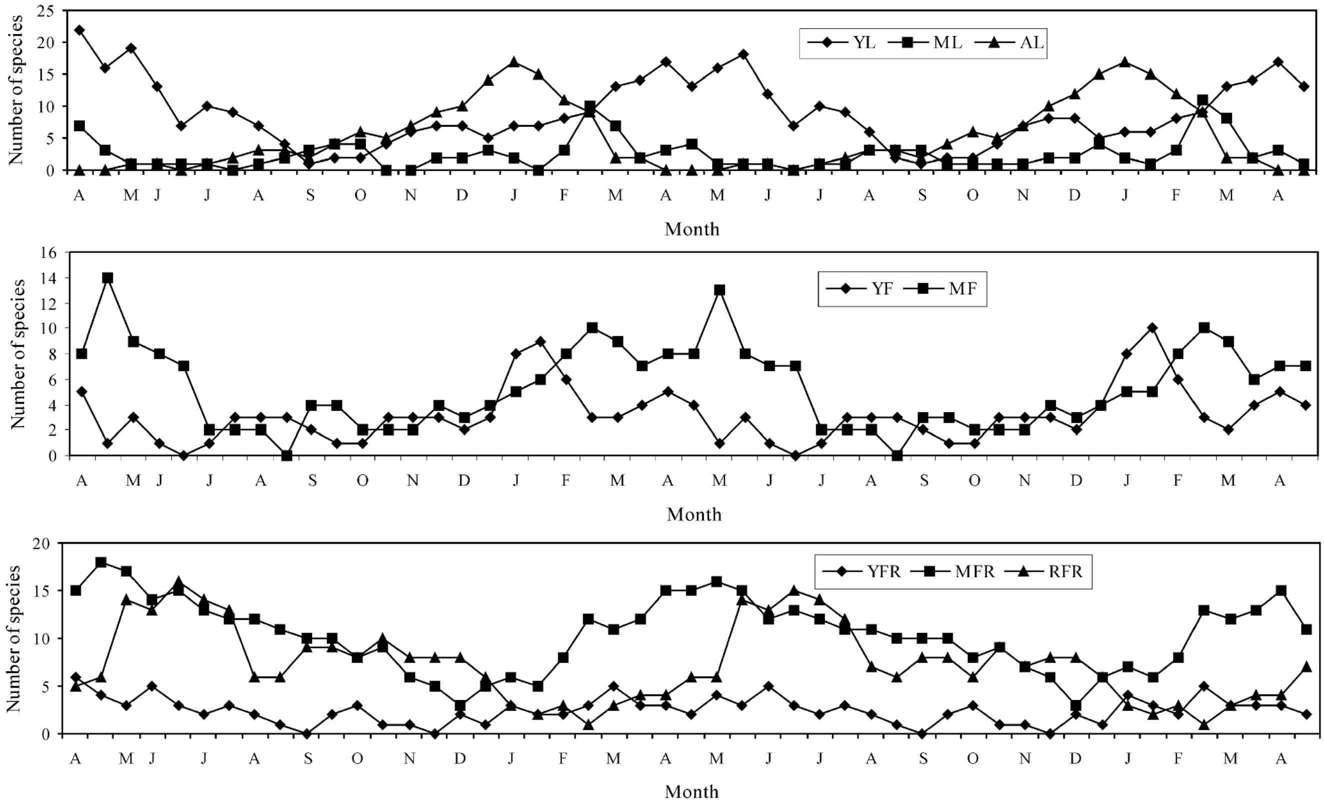

Figure 2. Phenology of tree species in tropical forests at Kodayar, Western Ghats, Tamil Nadu; YL, Initiation of leaf; ML, Maturation of leaf; AL, Abscission of leaf; YF, Initiation of Flowering; MF, Flower maturation; YFR, Initiation of fruiting; MFR, Maturation of fruits; RFR, Ripening of fruits.

Table 2. Phenological patterns of tree species in relation to rainfall, maximum and minimum temperatures in tropical forests at Kodayar, Western Ghats Tamil Nadu

		Environmental factor		
		Rainfall	Max. temperature	Min. temperature
Phenophase	Species	Spearman's rank correlation coefficients (r_s)		
Leaf initiation	Deciduous	0.006	0.527	0.345
	Evergreen	–0.061	–0.025	0.165
Leaf abscission	Deciduous	0.071	–0.490	–0.264
	Evergreen	–	–	–
Flower initiation	Deciduous	–0.41*	0.610*	0.639*
	Evergreen	0.099	0.165	–0.099
Flower anthesis	Deciduous	–0.066	0.570	0.311
	Evergreen	–0.437*	0.253	0.135
Fruit initiation	Deciduous	0.294	0.377	0.346
	Evergreen	–0.033	0.404	0.377
Fruit ripening	Deciduous	0.374	–0.384	–0.286
	Evergreen	0.743*	–0.084	–0.073

*$P < 0.05$.

ever, flower-bud initiation activity continued throughout the year with a small peak of activity in July, August and November. Flower maturation also showed two peaks: a larger one in February–May and a smaller one in September. Most species bloomed once a year and flowering activity (starting from bud inception to full-bloom phase) of these species was seasonal. However, species such as *D. latifolia*, *P. marsupium*, *Mallotus philippensis*, *Isonandra lanceolata* and *Fagraea ceulanica* produced flowers for several months, covering more than one season (extended flowering). Generally, flowering pattern in *Dalbergia* and *Pterocarpus* is annual in several sites in the Western Ghats. However,

Table 3. Classification of tree species based on flowering phenology in tropical forests at Kodayar, Western Ghats, Tamil Nadu

Continual	Sub-annual	Annual	Others
Fagraea ceilanica (A)	*Dalbergia latifolia* (W)	*Anogesissus latifolia* (E)	*Dimocarpus longan* (A)
Isonandra lanceolata (A)	*Pterocarpus marsupium* (W)	*Aporosa lindleyana* (W)	*Dipterocarpus indicus* (W)
Mallotus philippensis (A)		*Artocarpus heterophyllus* (A)	*Hopea parviflora* (W)
		A. hirsutus (A)	*Hydnocarpus alpina* (A)
		Baccaurea courtallensis (A)	*Vateria indica* (A)
		Berrya cardifolia (A)	
		Bridelia crenulata (A)	
		Buchanania lanzan (A)	
		Careya arborea (A)	
		Cassia fistula (A)	
		Diospyros bourdillonii (E)	
		Dillenia pentagyna (A)	
		Emblica officinalis (A)	
		Gluta travancorica (A)	
		Grewia tiliaefolia (A)	
		Helicteres isora (E)	
		Holarrhena pubescens (A)	
		Ixora brachiata (A)	
		Macaranga peltata (A)	
		Memecylon talbotianum (A)	
		Olea dioica (A)	
		Sapindus emarginatus (A)	
		Syzygium laetum (A)	
		Syzygium mundagam (A)	
		Tabernaemontana heyneana (A)	
		Terminalia arjuna	
		T. bellirica (A)	
		T. chebula (A)	
		T. paniculata (W)	
		T. tomentosa (A)	
		Vitex altissima (W)	
		Xanthophyllum flavescens (A)	

Letter in parenthesis indicates mode of fruit dispersal (A, Animal; W, Wind; E, Explosive).

they may flower twice under special occasions, such as a dry spell between two rainfall peaks. The activity of flower initiation of deciduous species showed negative correlation ($r_s = -0.416$; $P < 0.05$) with rainfall, but minimum and maximum temperature showed positive significant correlation ($r_s = 0.639$; 0.610; $P < 0.05$ respectively). Similarly, the activity of flower maturation in evergreen species showed negative correlation ($r_s = -0.437$; $P < 0.05$) with rainfall. Flower anthesis in deciduous species showed positive correlation ($r_s = 0.571$; $P < 0.05$) with maximum temperature. A similar seasonality (dry-season flowering) has also been observed in tropical forests[7,18]. However, such seasonality in flowering could not be recognized in the forests of Malaysia[22]. Massive pre-monsoon flowering also means continued availability of energy in the subsequent rainy season for developing fruits, when the foliage is actively photosynthesizing[18]. Two peaks (larger one during the dry period and smaller one during the rainy season) were observed in the present study in case of emergence of flower buds and floral anthesis. Similarly, two peaks of flowering activity, one extensive period during the long dry season and the second corresponding to the onset of rainy season have been reported for the Costa Rican forest[2]. Flowering in different seasons may be attributed to avoid competition for pollinators[8,10]. Classification of tree species based on the flowering phenology is presented in Table 3. Among the 42 tree species, 3 are continual, 2 are sub-annual, 32 species are annual and the remaining 5 are under the category of supra-annuals (one flowering episode followed by a non-flowering interval). In the present study, *Vateria indica*, a member of Dipterocarpaceae, did not produce reproductive parts during two years of observation. Similarly, *H. parviflora* and *Dipterocarpus indicus* (members of Dipeterocarpaceae), produced flowers and fruits once during the three years of field study. *Dimocarpus longan* and *Hydnocarpus alpina* also produced flowers and fruits once in two years of observation. Similar observations were made, and it was reported that occasional flowering with an interval of about 3–8 years is more common in Dipterocarps[23].

The activity of fruit initiation was observed throughout the year (Figure 2). It showed two small peaks, one in March and the other in June. Fruit maturation and ripening was also observed throughout the year. However, peak activity of fruit maturation was recorded during March–May, while fruit ripening was during May–July. *M. philippensis*, *I. lanceolata* and *F. ceilanica* had an extended flowering activity and showed fruit initiation during more than one season, whereas *D. latifolia* and *P. marsupium* produced fruits twice a year. In most of the species fruit fall occurred after ripening, while *T. paniculata*, *T. arjuna* and *T. tomentosa* retained their fruits until the emergence of new flowers. In majority of the species, fruit ripening was close to the onset of rainfall or at the onset of early rainy season (May–July), as also indicated by the correlation between fruiting phenology and rainfall ($r_s = 0.743$, $P < 0.01$; Table 2). Others also observed it elsewhere in the tropics[10,23]. The species within any given guild showed no significant or complete overlap in fruiting phonologies (Table 4). These phenomena could be attributed to enhance dispersal, escape predation and avoid pathogen infection[6]. Animal-dispersed (16) species showed seasonal fruit ripening during rainy season I (May–August), while many wind-dispersed species (6) showed seasonal fruit ripening during second rainy season (September–December; Table 5). A significant positive correlation ($r_s = 0.079$, $n = 30$, $P < 0.05$) was also found between fruit ripening in animal-dispersed species and rainfall. Another explanation for animal-dispersed species to fruit during the rainy season is to maintain moisture in the fruits and also to regenerate during the rainy months. Odd-season ripening of fruits in some of the hard seed-coated species such as *T. bellirica*, *T. chebula* and *E. officinalis* may help dispersal, since many of these were ingested by animals and dropped elsewhere[6,7]. At the community level, fruit fall peaked during the first rainy season (May–August) in most of the species observed. This could be attributed to utilization of available soil moisture for seed germination and seedling establishment[18]. Wind dispersed ($r_s = -0.185$, $n = 8$, $P > 0.05$) and explosively dispersed ($r_s = -0.447$, $n = 3$, $P > 0.05$) fruiting guilds showed no significant correlation with rainfall. This may be to take advantage of the dry spell and wind flow during the early summer. In case of explosively dispersed fruits, they might have adapted to dehisce during the dry months when relative humidity is low[10].

Leaf flushing in the dry season or pre-monsoon season took full advantage of the rainy season for productivity. Flowering showed negative correlation with rainfall; such a seasonal activity could be to attract pollinators. Fruit-ripening phenology showed a positive correlation with rainfall, which could be due to the soil moisture availability for seed germination and seedling establishment, and could be an adaptation to animal dispersal. Therefore, the present study revealed that the vegetative and reproductive phenologies of tree species are adaptations to the surrounding abiotic and biotic environment.

Table 4. General overlap indices in different fruiting guilds in tropical forests at Kodayar, Western Ghats, Tamil Nadu

Dispersal mode	Overlap index	N	d.f	χ^2	Significance (5%)
Animal	0.472	30	58	229.11	NS
Wind-dispersed	0.507	7	12	44.88	NS
Explosive	0.636	3	4	19.2	NS

NS, Not significant at 0.05 level.

Table 5. Dispersal guild (mode of dispersal) wise variation in fruit ripening of tree species in tropical forest at Kodayar, Western Ghats, Tamil Nadu

	Seasonality of fruit ripening		
Dispersal guild	Dry season (January–April)	Rainy I (May–August)	Rainy II (September–December)
Animal-dispersed tree species	3	16	9
Wind-dispersed tree species	3	3	5
Explosive tree species	2	2	1

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Effect of protection on regeneration in some selected village forests under community protection in Uttara Kannada district, Karnataka, India

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Effect of protection on regeneration and species similarity was studied in six village forests under Joint Forest Management in Uttara Kannada district, the Western Ghats. Difference in species number, stem density, basal area of planted and natural species, and shrub density was compared between two observations in all the villages studied. All village forests experienced a decrease in the number of stems after the protection was withdrawn. The decrease in overall density of natural species was more (19.7%) than that of the exotic species (8.2%). This could be because of the utility of native species than the exotic ones. Basal area increased for stems that were planted, while it generally decreased for stems of natural species. The overall basal area, including native and planted species, had increased during the observation period indicating biomass accumulation. Shrub density increased in all villages except in Kadle, where there was no natural vegetation in the village forest. Greater similarity of species was found for planted species within the same village forests before and after protection. The number of cut stems increased significantly when the protection was removed, indicating diversion of pressure. The community did not prefer exotic species that were planted and on the other hand the native species were used to meet various biomass needs. The study indicates that the programme should develop strategies that incorporate various measures to conserve and maintain the village forests.

ONCE forests used to be a major resource in the past, but with increase in population, pressure on the forests has increased to meet the growing needs of industrialization and urbanization[1–5]. Now the forests are unable to meet even the basic needs of the forest-dependent communities. Continued deforestation has put increasing pressure on the natural resources and on the livelihood patterns of the forest-dependent communities. A study on deforestation has concluded that forest policies have contributed significantly in conserving forests in India[6–10]. The policies include the Wildlife Act 1972, Forest Conservation Act 1980, and the Forest Policy 1988. The last two policy pronouncements triggered several afforestation programmes.

Participatory forestry programme called as Joint Forest Management (JFM) was launched in India during 1990 with a view to enhance regeneration of degraded forests and accord protection through local community. The effort towards community-initiated forest protection has emerged as a movement in India with over 62,000 village communities protecting over 14.4 mha of forests[11]. Though the efforts are largely from the government, the impact of such efforts on the ecology is not properly understood[12,13]. The programme now is over a decade old and no attempt has yet been made to understand the impact of protection towards vegetation recovery, regeneration potential and species composition either at the local, regional or national level[12,14].

In Karnataka, the programme of participatory forestry is called the Joint Forest Planning and Management (JFPM). A guideline was issued in the state to undertake participatory community forestry during 1993 through an order based on the guidelines passed from the Government of India. Plantations under JFPM were raised with a view to supply fuelwood, fodder and other non-timber forest products to the local people living in and around the forests. These plantations were also expected to improve tree cover and allow natural regeneration due to the protection provided jointly by local people and the Forest Department. The implicit assumption in the community protection is to improve regeneration in these forests, as a low cost option and meeting

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