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Studies on the effect of fire on moist deciduous forests

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Contents

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ABSTRACT

Seasonal fire occurrence is a common phenomenon in the moist deciduous forests. In order to study the impact of fire on moist deciduous tree species a study was carried out in an area located in the moist deciduous forest (MDF) of Thrissur Forest Division. Important moist deciduous tree species were selected and their fire hardiness in respect of bark thickness, moisture content and tissue composition was studied in various age groups *viz*. seedlings and trees. Branching pattern, canopy structure and bole nature were also studied to understand their fire resistance capacity. The results reveals that the nature of bark or moisture content do not directly contribute to the fire resistance of the individual species.

As an effort to find out fire resistant species for regeneration and afforestation activities in the fire prone areas, a series of nursery studies on stump regeneration, using stumps of MDF species having different collar diameter was carried out. In order to understand their fire survival efficiency and regeneration capacity, a field trial using stumps of the same species was also carried out. The results obtained indicated that thicker stumps, having a diameter range of 2-3 cm at their collar region is better than thinner ones (diameter 1-2 cm) for survival and regeneration. Also species like *Gmelina arborea* and *Pterocarpus marsupium* which are more fire resistant in terms of survival after fire were found to be suitable for re-vegetation activities.

In order to understand the response of tree seedling populations to fire, two set of controlled burning experiments were carried out during two different seasons *viz.* immediately after monsoon and during early summer. The studies revealed that the tree seedlings show increased fire survival with corresponding increase in their age and that higher intensities and higher frequencies of fire are detrimental to the regeneration of populations, in terms of their survival. Systematic fire ecological research on the moist deciduous forest ecosystem is very essential to evolve economically viable low-risk fire management strategies.

1. GENERAL INTRODUCTION

One of the major causes of degradation and desertification of forest areas is the recurrent incidence of fire, around the world. In India, the deciduous forests constitute about 70 percent of the total forest vegetation (Forest Survey of India, 1989). These forests are mostly under continuous influence of fire due to seasonal increase in temperature and accumulation of litter. The evergreen forests are also prone to fire, if left unprotected.

Fire causes extensive damage not only by affecting regeneration and stocking, but also interferes with the quality and value of the standing timber (Swarupanandan and Sasidharan, 1992). It also affects the soil nutrients status as it burns the humus layer on the one hand and adds ash on the other (Brown and Davis, 1973). It is also known to affect species diversity, density and biomass (Bisett and Parkinson, 1980).

Forest ecological studies have always stressed on fire ecology and it has even advanced to the application phase recently, the knowledge being used for obtaining desired species composition in stands. However, fire ecological studies remain an unexplored or under explored area in the Indian context and the studies in the country being mostly limited to fire combating only. The forest ecosystem research in India should be provided an orientation such that the knowledge on the response of different vegetation to fire could be utilized for practical forest management.

The use and upkeep of forest resources largely depend upon the structure and diversity of forests which is very different in the tropics and temperate regions. The existing socio-economic conditions of a country also contribute to this to a great extent. Reasons for frequent occurrence of fire are many, but among them the anthropogenic ones are also very important, especially in the tropics. Because of the varied reasons of fire and considering the vastness of the area to be protected, total prevention of forest fires is often not achieved. Alternatively, along with fire protection, measures to minimize and compensate the deteriorating effects of fire also need to be devised (Swarupanandan and Sasidharan, 1992).

The response of each component of forest vegetation to forest fires need to be studied in detail, for the effective management. The present study attempts to look into some aspects with the following objectives:

1. To identify fire tolerant and fire hardy tree species in the moist deciduous forests
2. To test and develop the stump planting technique for the selected species
3. To asses the fire survival ability and regeneration of forest vegetation and to study their response to fire exclusion.

2. FIRE HARDINESS OF COMMON MOIST DECIDUOUS TREES

2.1. INTRODUCTION

The susceptibility of forest trees to fire and their response after the fire incidence is generally dependant on their intrinsic characteristics, the nature of the environment in which they occur and the nature of fire to which they are exposed. The capability of forest trees to evade the ill effects of forest fire is dependent on the degree of development of protective mechanisms and their effectiveness. Bark features, branching pattern, branch and bark shedding, occurrence of dry, persistent limbs on the bole, etc. are some such features which determine the extent of fire susceptibility. The growth stage of the tree and the ability for tissue regeneration are other important factors.

It has been found in a number of studies that the morphological and physical characteristics of bark have much to offer in providing a protective insulation to living trees. In addition, the bole characteristics such as the presence or branches or branch stubs at lower height levels are also important in transmitting the fire to the canopy. Hence, these features have also been investigated in the present study to characterize the fire resistance of the MDF tree species.

2.2. MATERIALS AND METHODS

The following common tree species of the moist deciduous forest ecosystem were selected for the study of bark and bole characteristics.

1. *Bombax ceiba* L.
2. *Dalbergia latifolia* Roxb.
3. *Dillenia pentagyna* Roxb.
4. *Grewia tiliifolia* Vahl
5. *Lagerstroemia microcarpa* Wt.
6. *Pterocarpus marsupium* Roxb.
7. *Tectona grandis* L.f.
8. *Terminalia crenulata* (Roth.) Cl.
9. *Terminalia paniculata* Roth.
10. *Xylia xylocarpa* (Roxb.) Taub.

The morphological features of trees and saplings, such as bark surface features, branching position and branch shedding behaviour were recorded during field studies. For determination of bark thickness and moisture content, 4 cm x 4 cm pieces of bark were chiseled out from standing trees and saplings. Since trees of all intermediate diameter classes were not available in adequate numbers, sampling was restricted to two classes; i.e., diameter classes 10-20 and 20-40 cm. Bark samples were collected both from BH and stump (15-20 cm from ground) levels of each tree. At least 5 trees were sampled per diameter class for each species after noting the tree diameter. Bark thickness was measured to millimeter accuracy in the field itself. For moisture content determination, samples were weighed accurately without allowing moisture loss and then oven-dried at 105°C for 48 hrs. From the weight difference moisture content percentage (M.C. %), expressed as percentage of oven-dry weight, was computed. For the study of bark regeneration the 4cm x 4cm slots on bark surface of trees left after removal of samples were examined after 6 months. The tangential width of the gap between either flanks of the wound was measured in relation to the original width to calculate the percentage of wound closure.

2.3. RESULTS AND DISCUSSION

Unlike the fire-prone vegetation comprising both coniferous and hardwood forests with several features congenial to intense fire damage (Chandler *et al*., 1983), most MDF tree species examined in the present study had characteristics which may be regarded as advantageous from the point of view of resisting recurrent surface fires. The morpho-ecological characteristics that offer fire resistance to vegetation and individual trees have been reviewed in various publications (Brown and Davis, 1973, Chandler *et al*., 1983; Kauffman and Martin, 1990). Based on these, the following observations on the common moist deciduous tree species are of interest from the angle of their fire resisting ability.

2.3.1. BARK FEATURES

By far, bark is regarded as the most effective protective mechanism in a tree. It is an excellent insulating material against fire (Brown and Davis, 1973), which also offers protection from mechanical and pathological damage to vital tissues like cambium. Bark characteristics are variable depending upon species, tree age and growth habitat. Accordingly, its insulating properties also differ.

Bark surface characteristics

The surface texture of bark of common MDF tree species ranged from very smooth (as in *Lagerstroemia microcarpa*) to very rough and scaly with cracks and fissures (as in *Terminalia crenulata*). The bark surface was spiny in saplings and young trees of *Bombax ceiba*, which later became fairly smooth, as the trees grew older. *Lagerstroemia microcarpa* was conspicuous as regards the seasonal bark shedding in the form of thin sheets. Rest of the species examined showed varied degree of surface roughness. The precise effect of such surface irregularities like tissues, cracks, *etc*. are not known (Brown and Davis, 1973). Nevertheless, they are considered important in transmitting heat to the cambial zone (Martin, 1963). It has been found that the rough stringy bark of some eucalypts ignites more readily as compared to smooth, moist bark during fire incidence (Gill *et al*., 1986). However, it was found during the controlled burning experiments in the present study that bark surface texture of MDF trees showed no pronounced effect on stem surface ignition except that the loose surface flakes got charred more readily as compared to smooth bark. Thus the damage to young and mature trees was limited to a superficial charring of dead, dry bark surface; edges of raised scales and tips of spines (in *Bombax ceiba*) up to a height of 50-75 cm in some trees during mild surface fires.

Bark thickness

The thickness of bark is the most important index governing the relative resistance of a tree to fire (Brown and Davis, 1973; Chandler *et al*., 1983; Gill, 1995). Death of trees due to fire is mostly because of the heat flux reaching the cambial zone exceeding the threshold level (Gill, 1974). This causes the cambial death; sloughing of the bark, attack by insects and decay fungi ultimately resulting in hollow stems or dead trees (Toole, 1965). Trees with a thick bark show lower maximum cambial temperatures, longer time to reach peak temperatures, slower rate of heat loss and shorter time until surface ignition. Thus, bark thickness is a good indicator of a tree's ability to protect its tissues from fire injury (Hengst and Dawson, 1994). Several studies have shown a positive relationship between bark thickness and fire resistance of trees (Engstrom and Mann, 1991; Harmon, 1984; Martin, 1963).

The average values of bark thickness at BH and stump levels of saplings (dia 5-10 cm) and mature trees (dia 20-60cm) of common MDF tree species are given in Table 1. It is seen that among the different species examined, bark thickness was either greater at stump level or almost equal at stump and BH levels. Among the different species, bark thickness was the lowest in *Lagerstroemia microcarpa* possibly owing to repeated abscission of its outer layers every year. *Terminalia crenulata* and *Bombax ceiba* had the thickest bark. *Tectona grandis* and *Grewia tiliifolia* also had fairly thick bark although, next only to the former two species. Among the two diameter classes compared, bark thickness was greater in mature trees than in saplings or young trees. This observation is in conformity with earlier studies by Martin (1963), Harmon (1984), Gill and Ashton (1968) and Hengst and Dawson (1994) who have shown a direct relationship between stem diameter and bark thickness. Obviously the extent of fire damage to a tree is also dependent on the stem diameter.

Table 1. Average bark thickness (cm) at BH and stump levels of saplings and mature trees of common MDF tree species.

Species	Bark thickness (cm) of saplings		Bark thickness (cm) of mature trees	
	Stump level	BH level	Stump level	BH level
Bombax ceiba	1.20 (0.24)	0.86 (0.25)	2.20 (0.47)	1.90 (0.36)
Dalbergia latifolia	0.6	0.6	1.2	1.1
Dillenia pentagyna	*	*	1.28 (0.32)	1.26 (0.22)
Grewia tiliifolia	0.84 (0.05)	0.7(0.07)	1.78 (0.3)	1.58 (0.36)
Lagerstroemia microcarpa	0.5	0.3	0.88 (0.19)	0.94 (0.09)
Pterocarpus marsupium	0.9	0.7	1.8 (0.52)	1.85 (0.35)
Tectona grandis	1.04 (0.11)	0.94 (0.21)	1.83 (0.15)	1.87 (0.15)
Terminalia crenulata	*	*	2.02 (0.36)	2.00 (0.22)
T. paniculata	0.66 (0.18)	0.52 (0.13)	1.42 (0.27)	1.34 (0.32)
Xylia xylocarpa	0.60 (0.2)	0.50 (0.17)	1.44 (0.43)	1.4 (0.31)

Figures in parentheses show standard deviation. * not measured.

Moisture content of bark

Bark moisture content (M.C. %) is yet another important factor directly influencing the fire damage to the cambial tissue. Moisture content of the bark affects its flammability, which is a promoting factor to heat influx to the cambial zone (Gill and Ashton, 1968; Gill *et al*., 1986). Bark moisture content also influences thermal properties like specific heat; thermal conductivity and diffusivity (Martin, 1963), which determine the heat transfer to the cambial zone.

The average M.C. % of bark of the common moist deciduous tree species varied in the range of 75-360% (Table 2). No marked difference was noted in the moisture content between the stump and BH levels. It was found that *Terminalia crenulata* had the lowest moisture content of <80% among the different species. This is because bulk of its outer layers was made up of dead, persistent corky tissue having very low moisture content. On the other hand, in *Bombax ceiba*, another species having thick bark, the average moisture content of young trees and saplings was usually greater (i.e., more than twice as that of mature trees, in some species like *Pterocarpus marsupium* and *T. crenulata*) than that of mature trees. The reason is obvious; the relative proportion of living tissue was greater in younger bark as compared to that of mature trees.

Table 2. Average moisture content percentage (M .C. %) of bark in saplings and mature trees of common moist deciduous tree species.

Species	Bark M .C. % of Saplings		Bark M .C. % of mature trees	
	Stump level	**BH level**	**Stump level**	**BH level**
Bombax ceiba	397.55(58.97)	302.96(29.88)	294.42(72.42)	276.21(60.49)
Dalbergia latifolia	282.67	279.81	142.49	146.52
Dillenia pentagyna	*	*	187.53(23.10)	163.70(16.20)
Grewia tiliifolia	244.58(39.78)	252.14(30.39)	204.88(60.30)	210.72(35.75)
Lagerstroemia microcarpa	285.78(26.46)	244.21(38.49)	195.18(23.91)	194.35(17.55)
Pterocarpus marsupium	447.75	432.20	174.68(48.19)	181.25(26.08)
Tectona grandis	316.77(37.46)	321.36(20.53)	200.80(12.76)	173.51(8.83)
Terminalia crenulata	*	*	75.71(15.22)	77.20(23.55)
T. paniculata	213.26(55.45)	230.53(65.55)	127.48(51.90)	103.12(29.70)
Xylia xylocarpa	302.34(51.80)	258.95(42.69)	171.62(27.89)	152.23(17.33)

Figures in parentheses show standard deviation.

- not measured**.**

All these observations suggest that the moisture content of the bark is variable due to its tissue constitution and proportion of phloem and corky tissues in it. The relative thickness or thinness of bark does not seem to affect its moisture content although it has been observed in some hardwoods that moisture content is low for thin bark (Hengst and Dawson, 1994).

Bark tissue regeneration

The ability of trees to regenerate the tissues that are heat killed or damaged during fire incidence is also an important factor influencing their recovery. In mature stems where the canopy escapes fire, the tissues that are commonly affected are bark and cambium. If the stem injury is only partial, in the form of a wound or scar, there is a recovery response by callus growth towards wound closure. Therefore, in the present study, the square slots left on the stem after removal of bark samples were simulated to fire wounds for a comparison of wound healing response of the MDF trees. The average width of the wound callus formed after a span of six months from the date of bark removal was measured. The tangential width of the wound closure ranged from as low as 2.5% in *Dalbergia latifolia* to 100% as in *Terminalia crenulata. Pterocarpus marsupium* and *Xylia xylocarpa* showed 37.5% and 34.4% of wound closure respectively. In rest of the species the value ranged from 78.5% (*Lagerstroemia microcarpa*) to 98.3% (*Bombax ceiba*) with intermediate values of 85% (*Dillenia pentagyna*), 86 %(*Tectona grandis*), 92.1% (*Terminalia paniculata*) and 97.5% (*Grewia tiliifolia*). However, these values are to be taken only as an indication as they are not based on intensive measurements on different girth classes in adequate replicates. It is logical that there is likely to be variation among species in their wound healing response depending upon the size of the wound, time of wounding, tree age, growth conditions, etc. which have not been taken into consideration in the above analysis.

2.3.2. BRANCH ARRANGEMENT

Mature trees of majority of the moist deciduous tree species were usually devoid of branches or dead branch stubs at lower height levels of stem normally reachable even by intense surface fires (about 3m). In species such as *Bombax ceiba*, there was an orderly shedding of lower branches (self pruning) whereby the stem was without limbs up to considerable height. Among the species investigated, Grewia *tiliifolia, Tectona grandis, Xylia xylocarpa* and occasionally *Terminalia crenulata* were found to have live shoots or dead branch stubs at or below 3m height level in mature trees. However, these shoots were mostly minor which often arise from buds and they do not form a component of the main canopy. In rest of the species, branches were usually confined towards the canopy region and the lower, older branches are self-pruned as the trees grew in normal course. Thus there was very little chance of surface fire spreading into the canopy of mature trees except when thick shrubby undergrowth or dry stems of climbing vines readily burned and contributed to partial scorching of the crown. Among the MDF tree species studied *Xylia xylocarpa* was found to be remarkably poor in branch shedding habit; the dead, decaying stubs of lower branches remained attached to the stem even in mature trees. Such persistence of dead limbs on the stem is found to favour flammability. Trees that self-prune readily and develop high and open crowns are more successful in escaping fire damage because they accumulate less flammable material close to the stem (Brown and Davis, 1973)

2.4. CONCLUSIONS

Bark surface texture of MDF trees investigated did not show features promoting stem surface ignition except that the loose surface flakes of rough barks were prone to charring as compared to smooth bark. *Terminalia crenulata* and *Bombax ceiba* had the thickest bark and *Lagerstroemia microcarpa* had very thin bark possibly due to its branch shedding behavior. Invariably, bark thickness was greater in mature trees than in saplings or young trees. Obviously the extent of fire damage was also lower to mature trees. The moisture content of bark was not dependent on its thickness but was variable due to its tissue composition and proportion of phloem and corky tissues in it. Young trees and saplings usually had higher moisture content in their bark. The potential for bark regeneration was lowest in *Dalbergia latifolia* whereas other species were much efficient in this respect. With regard to bole characteristics, only some species such as *Terminalia crenulata*, *Grewia tiliifolia, Tectona grandis and Xylia xylocarpa* were found to have live shoots or dead branch stubs at or below 3m. height level in mature trees. In rest of the species, branches are usually confined towards the canopy region and the lower, older branches are self-pruned as the trees grow in normal course. Overall, most MDF tree species examined in the present study had characteristics which may be regarded as advantageous from the point of view of resisting recurrent surface fires.

3. STUDIES ON STUMP REGENERATION TECHNIQUE FOR FIRE SURVIVAL OF THE SELECTED MOIST DECIDUOUS TREE SPECIES

3.1. INTRODUCTION

The stump, which is 'the root and shoot pruned seedling', is used successfully as a planting material for raising plantations of many forest species. (Champion and Pant, 1931; Joshi1981; Troup, 1921) Stump planting has got many advantages over conventional method of planting the seedlings. They are convenient to transport, easy to plant and in general, quicker in initial growth with deep root development (Khanna, 1984). However, the success of this technique varies considerably with the species. Though, the technique of stump planting is well established for teak, many economically important species are yet to systematically studied for the feasibility of this method.

In a study conducted by Champion and Pant (1931) in India, using stumps of about 50 tree species, greater success in stocking by stump planting compared to direct sowing of seeds or transporting of seedlings, especially in hostile areas. Stumps were found to give higher survival percentage, better growth of shoots and were more resistant to insect pests, compared to seedlings.

The survival and growth of stump are influenced by many factors. The size and age of the seedlings used to prepare the stumps are two important factors (Joshi, 1981; Marcel, 1970). Better survival and growth of many moist deciduous tree species using stumps prepared out of 1-2 year old seedlings having collar diameter of 2.5 cm and taproot length of 10-20 cm was reported by Joshi (1981). In a similar study Marcel (1970) reported higher rate of survival and faster growth with stumps having 3-4 cm collar diameter rather than stumps with collar diameter less than 3cm.

Bombax ceiba Linn., *Gmelina arborea* Roxb., *Grewia tiliifolia* Vahl, *Lagerstroemia microcarpa* Wight., *Melia dubia* Cav., *Pterocarpous marsupium* Roxb., *Tectona grandis* L.f., *Terminalia bellerica* Roxb., *Terminalia crenulata* Heyme *ex* Roth., *Terminalia paniculata* Roth. and *Xylia xylocarpa* (Roxb.) Taub. are some of the dominant, fast growing and commercially important timber trees of the moist deciduous forests of the Western Ghats (Chandrasekharan,1962). Attempts have been made to raise plantations of these species, using stumps made out of six month old seedlings of some of the species, considering their economic and ecological importance (Rai, 1990). Many of these plantation trials met with little or no success, especially those in degraded areas, because of poor growth, which made them more susceptible to seasonal fires and various diseases (Dadhwal and Singh, 1983).

The present study on stump planting was undertaken on some selected tree species which are important in South Indian moist deciduous forests. The study mainly focuses on the regeneration ability of the species, when they are planted as stumps. Their potential for survival and growth in fire prone areas was also studied.

3.2. MATERIALS AND METHODS

3.2.1. Nursery experiments

Nursery trials were carried out using stumps prepared out of one- year- old seedlings of selected moist deciduous tree species in order to understand their efficiency to regenerate.

Preparation of stumps

In order to prepare the stumps for the experimental trials, seeds of the selected moist deciduous tree species listed below were collected and sown in raised nursery beds and enough number of seedlings were produced following the conventional method.

1. *Anogeissus latifolia* (Roxb.ex DC.)Wall.*ex* Guill. et Perr.
2. *Bombax ceiba* L.
3. *Gmelina arborea* Roxb.
4. *Grewia tiliifolia* Vahl
5. *Lagerstroemia microcarpa* Wt.
6. *Melia dubia* Cav.
7. *Petrocarpus marsupium* Roxb.

8. *Tectona grandis* L.f.
9. *Terminalia bellirica* (Gaertn.) Roxb.
10. *Terminalia crenulata* (Roth.) Cl.
11. *Xylia xylocarpa* (Roxb.) Taub.

When the seedlings attained one year growth in the nursery, they were uprooted and stumps were prepared by trimming away the shoot and roots using a sharp knife retaining the necessary portion, i.e. 1-2 cm shoot portion above the collar region and 10-15 cm tap root portion below the collar region. Care was taken not to damage the bark or dormant buds, while preparing the stumps. The prepared stumps were grouped into 2 different size classes depending on their collar diameter as follows.

Group 1. - Stumps with collar diameter = 1-2 cm.

Group 2. - Stumps with collar diameter > 2.0 cm. .

Prophylactic treatments

The stumps were treated with 0.05% Bavistin solution by dipping the lower portion in the solution for about an hour, in order to prevent fungal attack during regeneration. (Bavistin is a broad spectrum fungicide which contains carbendazim 0.5% a.i.). The stumps were given prophylactic treatment against termite attack using "Chlorpyriphos" 20% E.C. solution, by drenching the planted polythene bag, using a 0.05% solution diluted with water.

Planting

Stumps after sorting into two groups, were planted separately in polythene bags of 16 x 12 cm size filled with sand and soil in equal proportion (1:1) and kept in nursery. These were allowed to sprout and root properly. The stumps planted were kept in the shaded nursery beds and watered regularly. Excess watering and water logging were avoided.

Observations

Regular observations were made on sprouting, number of sprouts produced on each stump, height of stumps, number of new leaves produced and girth of the new shoots. After 60 days from the date of planting, the stumps were uprooted at random and the rooting responses were recorded as number of roots produced and length of roots per stump. The data collected were analysed statistically.

3.2.2. Field experiments

Selection of area

An area of about 0.75 ha was surveyed and demarcated in a poorly stocked moist deciduous forest area at Channakkad in Pattikkad Range of Trichur Forest Division. The area was divided into two equal plots of 0.37 ha (70m x 50m) size. Both the plots were provided with barbed wire fencing and fire line around them in order to prevent grazing and seasonal fires.

Selection of species

Based on the responses obtained in stump regeneration trials carried out in the nursery, all the eleven species were selected for field experiment also.

Preparation of stumps

1-2-year old seedlings of the selected MDF species, grown in the nursery, were used for preparing stumps. Seedlings from raised nursery beds were uprooted carefully, without causing damage to the taproot. The seedlings were then grouped as follows.

1. Seedlings with stem diameter <1.5 cm at the collar region.
2. Seedlings with stem diameter >1.5 cm at the collar region.

After grouping, stumps were prepared out of these seedlings by severing away the shoot and root portion after retaining the required length of tap root and shoot portions.

Two groups of stumps were thus prepared for field trials as listed below

Sl No.	Collar diameter (cm)	Shoot height (cm)	Tap root length (cm)	Total length (cm)
1	<1.5	2.5	15	17.5
2	>1.5	2.5	30	32.5

Field planting

A linear design of planting was followed with three replicates. A planting line having 1.5 m width was cleared off and pits of size 30 x 30 x 30 cm were taken at 1minterval. 3 m spacing was also provided between lines of planting. Planting was started in the month of June 1997 (immediately after the onset of southwest monsoon) and was completed by the end of the month. Pits were taken sufficiently early before planting and were treated with 0.05% chlorpyriphos solution as a prophylactic measure against termite attack. Stumps were planted vertically and were labeled individually. Soil working was carried out around each pit to avoid any water logging.

Observations

Observations were recorded as the performance of stumps, by taking note on the number of stumps sprouted, total numbers of sprouts, height of sprouts and number of new leaves on each stump. Girth of shoots was also noted above the transition region. After 60 days sample stumps were uprooted at random and observations were recorded on the number and length of roots and percentage of rooting as well as mortality.

3.2.3 Analysis

The data collected were subjected to statistical analyses using ANOVA and presented.

3.4. RESULTS AND DISCUSSION

3.4.1. Nursery Experiments

The result obtained in various treatments of stumps in the nursery trials and field trials are presented below.

Regeneration capacity and survival

Regeneration was more than 90 percent in stumps of all the species tried except *Bombax ceiba* in which it was 80 percent , with thicker stumps (2-3 cm collar diameter) and 60 percent with thin stumps (1-2 cm collar diameter; Table1) Results in other species were at par with regard to the percentage of survival. Similar results were also obtained for *Eucalyptus tereticornis* (Chacko *et al*., 1984).

Speed of sprouting

The speed of sprouting (number of days needed for the appearance of the first sprout on the stump) recorded in stumps revealed that treatment had no significant effect. Interestingly, sprouting was delayed in *Bombax ceiba* (16 days) compared to other species, which sprouted with in 5-7 days after planting, while *Grewia tiliifolia* needed only 4 days for initiation of sprouts (Table1)

Height of shoots

The mean height of shoots on the stumps (shoots regenerated from the planted stumps) at the end of 90 days after planting indicated that *Melia dubia* produced tallest shoots (63.9 cm) compared to other species , whereas *Bombax ceiba* had the minimum (25.4 cm) mean shoot height (Fig.1). Treatment had significant effect on height growth of the shoots except in *Grewia tiliifolia*, the rate of which was apparently higher with thicker stumps (2-3 cm diameter) for all the species studied.

Table 1. Speed of sprouting and percentage of survival of stumps of selected moist deciduous tree species

Species	Treatment	Speed of sprouting	Survival percentage
Anogeissus latifolia	T1	5	92
	T2	5	98
Bombax ceiba	T1	16	60
	T2	15	80
Gmelina arborea	T1	5	96
	T2	5	100
Grewia tiliifolia	T1	4	100
	T2	4	96
Lagerstroemia microcarpa	T1	6	92
	T2	6	92
Melia dubia	T1	5	92
	T2	5	100
Pterocarpus marsupium	T1	7	92
	T2	6	96
Terminalia bellerica	T1	6	100
	T2	6	96
Terminalia crenulata	T1	6	100
	T2	6	100
Tectona grandis	T1	5	100
	T2	6	100
Xylia xylocarpa	T1	8	96
	T2	12	100

T1 – Stumps having collar diameter 1-2 cm;   T2 – Stumps having collar diameter >2 cm

Fig.1. Effect of stump diameter on height of sprouts of various MDF species

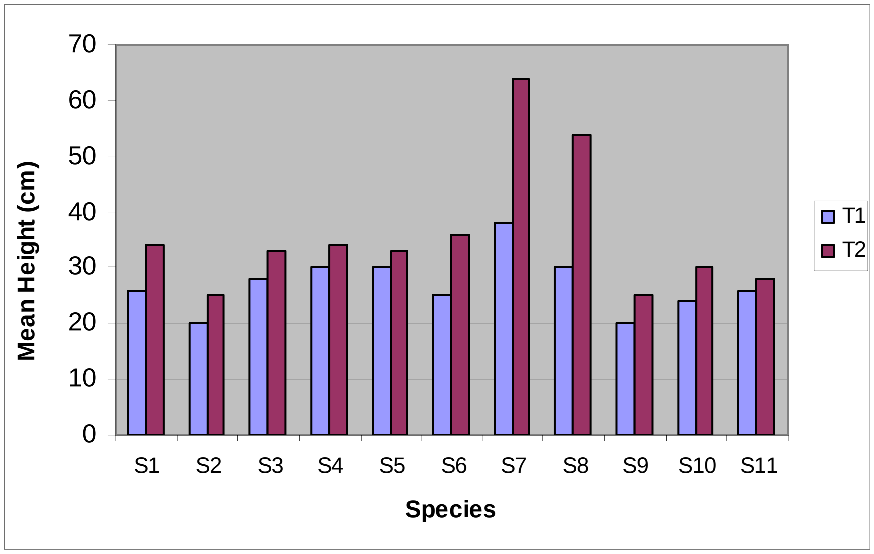
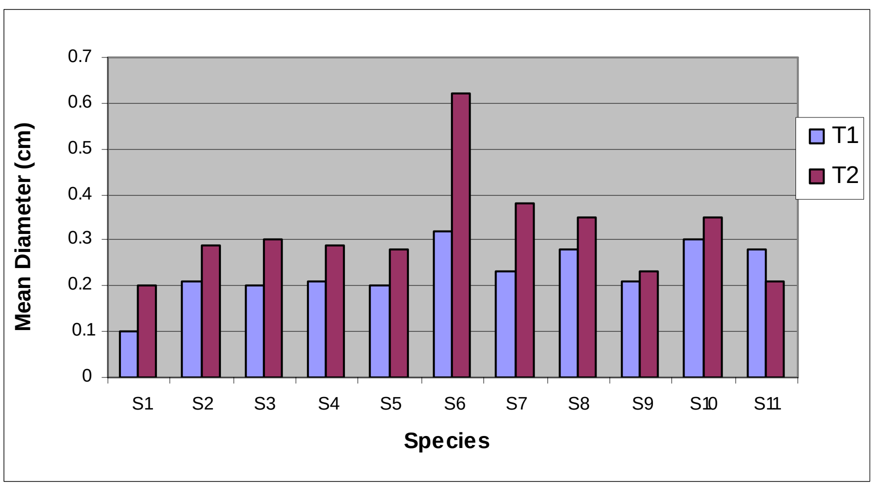


Fig. 2. Effect of stump diameter on diameter of new shoots produced by various MDF species.



T1-Stumps with collar diameter 1-2 cm; T2-Stumps with collar diameter 2-3 cm
S1- *Anogeissus latifolia*; S2- *Bombax ceiba*; S3- *Gmelina arborea;* S4-*Grewia tilifolia*; S5- *Lagerstroemia microcarpa*; S6- *Melia dubia;* S7-*Pterocarpus marsupium*; S8-*Terminalia bellerica*; S9- *Terminalia crenulata;* S10- *Tectona grandis*; S11-*Xylia xylocarpa*.

Diameter of shoots

Among the different species, *Melia dubia* recorded maximum mean diameter growth of shoots (0.63 cm), while those of *Lagetrsroemia microcarpa* and *Gmelina arborea* (0.19cm each) showed minimum growth (Fig. 2). Stumps with higher collar diameter (2-3 cm) in general, were found to perform better that the stumps with lower collar diameter (1-2 cm) in most of the species. However, the difference in stump diameter had no effect in the case of *Grewia tiliifolia* (Fig. 2).

Number of leaves

Data recorded as the number of new leaves produced on stumps indicated that the difference in diameter has no significant effect on the production of leaves on the shoots produced. However, thicker stumps generally produced more number of leaves, as this was proportionate to the height of shoots. The effect of treatment was much reflected in the case of *Melia dubia* and *Lagerstroemia microcarpa* (Fig. 3).

Fig. 3. Effect of stump diameter on production new leaves on the shoots of various MDF species.

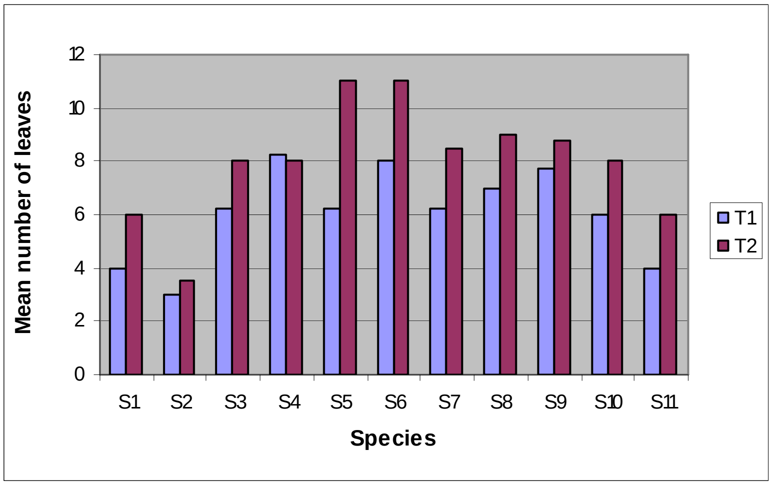
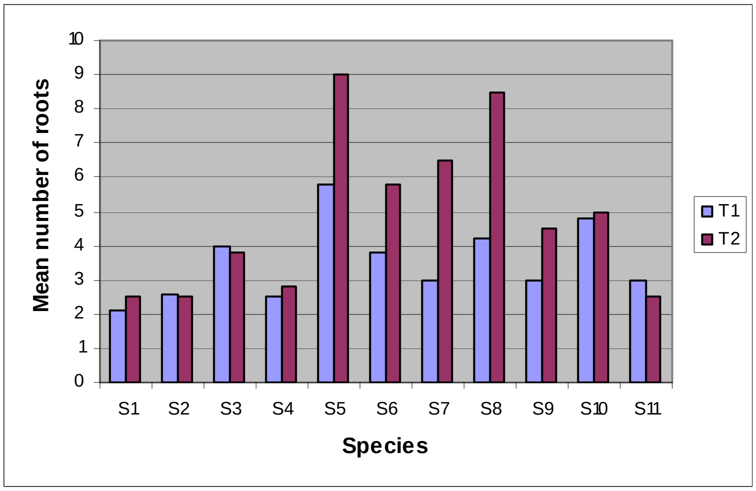


Fig. 4. Effect of stump diameter on number of root produced on stumps of various MDF species.



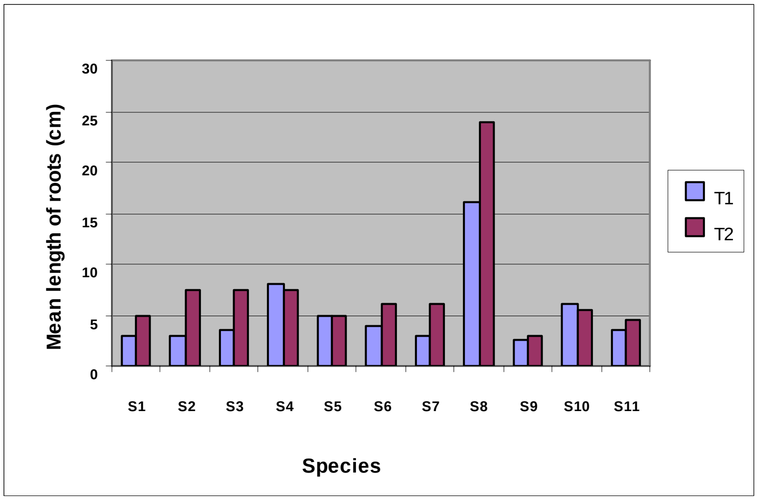
T1-Stumps with collar diameter 1-2 cm; T2-Stumps with collar diameter 2-3 cm

S1- *Anogeissus latifolia*; S2- *Bombax ceiba*; S3- *Gmelina arborea; S4-Grewia tilifolia*;

S5- *Lagerstroemia microcarpa*; S6- *Melia dubia* S7-*Pterocarpus marsupium*;

S8-*Terminalia bellerica*; S9- *Terminalia crenulata; S10- Tectona grandis*; S11-*Xylia xylocarpa*.

Fig.5. Effect of stump diameter on length of roots produced on the stumps of various MDF species



T1-Stumps with collar diameter 1-2 cm; T2-Stumps with collar diameter 2-3 cm

S1- *Anogeissus latifoli;* S2- *Bombax ceiba*; S3- *Gmelina arborea S4-Grewia tilifolia*; S5- *Lagerstroemia microcarpa*; S6- *Melia dubia;* S7-*Pterocarpus marsupium*; S8- *Terminalia bellerica*; S9- *Terminalia crenulata;* S10- *Tectona grandis*; S11-*Xylia xylocarpa*.

Number of roots

The thickness of the stumps was found to have significant effect on the number of roots produced in most of the species tried; thicker stumps (2-3 cm diameter) produced more number of roots (Fig. 4). In *Gmelina arborea* thinner stumps produced slightly more number of roots than thicker ones, but this difference did not turn out statistically significant. *Terminalia bellirica* and *Lagerstroemia microcarpa* produced maximum number of roots on the stumps (8.5 and 9.0 respectively), while it was minimum (2.3) in *Bombax ceiba.*

Length of roots

The maximum length of roots measured was 24.3 cm in *Terminalia bellirica* whereas it was minimum (4.4 cm) in *Terminalia crenulata* for the same treatment. The 2.3 cm thick stumps were significantly better than 1-2 cm thick stumps with regard to the length of roots in all the species except *Grewia tiliifolia* and *Lagerstroemia microcarpa* in which the difference in stump diameter did not show significant difference (Fig.5).

3.4.2. Field survival studies

Among the different treatments studied T2 (2-3 cm diameter of stump) showed maximum percentage (100) of survival compared to smaller diameter stumps. The stump of G. arborea, B.ceiba, P. marsupium and L .microcarpa exibited maximum percentage of establishment, where as the percentage of success was less with *Anogeissus latifolia*, *G. tiliifolia* and *T. crenulata* (Table.2). In general, stumps with thicker collar diameter (>2.0 cm) were found to withstand prescribed fire and showed better survival after fire. Among the different species tried, thick barked species such as *G. arborea* and *P. marsupium* were found to be more suitable for planting in fire prone areas.

The regeneration capacity of MDF species when they are planted as stumps, in terms of survival, speed of sprouting, height and diameter of shoots, number of new leaves and roots produced was found to be better in thicker stumps, compared to the thinner ones. Griffith (1941) observed similar trends in *Azadirachta indica, Feronia elephantum, Pterocarpus santalinus* and *Wrightia tinctoria* . The results obtained indicate that the thickness of the stump is a critical parameter that determines the regeneration efficiency, survival and early growth of stumplings.

Generally, thicker stumps have more carbohydrate storage in them, and this appears to be responsible for the quicker initial growth, as has been already reported by Shiroya *et al*., (1962). It has also been suggested that the accumulation of the carbohydrates close to the root collar region facilitates the development of profuse lateral roots (Hay and Woods, 1978). Production of more lateral roots may be advantageous, for better initial growth for stumps having only a strong taproot system with sparse lateral roots.

Table 2. Field survival of stumps of different diameter classes before (BF) and after (AF) the fire treatment

Sl. No	Treatments	Species										
	Particulars	Al	Bc	Ga	Gt	Lm	Md	Pm	Tb	Tc	Tg	Xx
1	No of stumps planted	15	15	15	15	15	15	15	15	15	15	15
	Stumps established BF (%)	0	100	93	13	93	60	100	60	33	80	47
	Stumps survived AF (%)	0	10	50	0	7	0	25	0	0	25	14
	Stumps resprouted AF (%)	0	80	50	100	79	100	75	78	60	75	86
2	No of stumps planted	15	15	15	15	15	15	15	15	15	15	15
	Stumps established BF (%)	20	20	100	40	93	100	100	93	27	60	60
	Stumps survived AF (%)	0	0	27	0	0	0	0	0	0	0	0
	Stumps resprouted AF (%)	0	0	60	80	100	100	100	79	11	78	78

Treatment 1- Stumps with collar diameter = 1-2 cm Treatment 2 - Stumps with collar diameter = 2 -3 cm

Al- *Anogeissus latifolia*; Bc- *Bombax ceiba*; Ga- *Gmelina arborea*; Gt - *Grewia tiliifolia*; Lm- *Lagerstroemia microcarpa*; Md- *Melia dubia*; Pm- *Pterocarpus marsupium*; Tb- *Terminalia bellerica*; Tc- *Terminalia crenulata*; Tg- *Tectona grandis*; Xx- *Xylia xylocarpa*

Thicker stumps are with more food reserves and this enables them to maintain live shoots over a period of time, compared to seedlings. In stumps, even if the shoots dry up during the dry season or in the adverse conditions like ground fire, because of the stored food reserves, they are able to regenerate in the succeeding favorable season (Champion and Pant, 1931). The advantage of using stumps instead of seedlings appears to be the efficiency of the former in capitalizing the stored resources needed for initial growth and development, which is crucial in competing with the adverse environment for survival.

3.5 . CONCLUSIONS

Attempts on re-vegetation of denuded or degraded areas are going on globally, on large number, mostly as plantation activities (Sunder, 1986). Replanting such areas with seedlings, often leads to little success due to the heavy mortality and poor survival rate. Stumps should be prescribed increasingly in such attempts, because of their proven superiority, so that the efforts meet with high rate of success.

Re-vegetation attempts involving a large number of plant species including many tree species also help to safeguard our biodiversity, through conservation. In areas where fire is a frequent annual phenomenon, planting thicker stumps of species appears to be better for higher survival rate and increased growth. However, the best suitable Silviculture practices for many of the moist deciduous tree species remain yet to be standardized. The present study points out the need for more detailed investigations on these aspects.

In most of the species studied, thicker stumps showed good survival percentage, increased height and diameter growth of shoots produced on them with more number of laves and profuse lateral growth. Variability in stump diameter did not show up an apparent effect on speed and percentage of sprouting. Since the stumps in general, have higher survival and growth capability, it appears to be advantageous to practice stump planting, i.e., re-vegetation activities whenever possible, instead of planting seedlings, in frequent fire prone areas.

4. SURVIVAL RESPONSE OF TREE SEEDLINGS

4.1. INTRODUCTION

Atmosphere and the biosphere are two major reserves of carbon and the element is always in a state of flux, being transported between these two reserves. Biologically fixed terrestrial carbon accumulated in living and dead biomass when dry or under arid weather is highly inflammable and tends to be released to the atmosphere in the form of its oxides - carbon dioxide and carbon monoxide. Almost all the forested ecosystems are subject of the risk of fire, no matter whether they fall under the protected, reserved, natural, managed, evergreen, deciduous, dry or cool forests, differing only in the intensity and periodicity, and the area subjected to fire each time.

Because of the characteristic life form, arborescent plants evade forest fire to some extent. This does not hold true in all situations, as the chemical composition of the biomass, both litter and standing biomass, has a deterministic role in inviting fire. Nevertheless, most vegetations display resilience to fire reflected in their post fire regenerative ability. While the combustibility of vegetation is a function of (a) species composition and (b) chemical composition of each of the species, resilience to fire is a function of the regenerative ability of the composed species, particularly fire hardiness of the seedling life stage.

Forest fire always involves the risk of immediate economic loss through the loss of valuable timber. Not only that, exposure of the ground to excessive light and radiation, acceleration of soil erosion, loss of soil biota and soil fertility, loss of diaspores that are the seed sources for the future vegetation, are its long-term effects on the biosphere; it also contributes to increase of carbon dioxide in the atmosphere and acceleration of the greenhouse effect.

Forests are reserves of living and dead biomass, important in cleansing and keeping up our environment, providing an array of timber and non-timber commodities of use to man and therefore, how these ecosystems could be safeguarded from the detriment of fire is a great concern both to the forester and the non-forester alike. The ultimate aim of forest-fire ecological research is this, so that both the environment and resource base is not impoverished.

Plants, contribute to the major share of the forest biomass. A closer look at the various objects of the forest ecosystem, their relative abundance, dominance, and role in inviting or recessing fire might be useful in evolving strategies for fire management or at least in minimising the detriment to the ecosystem. Continued fire control extending over several years has been reported to increase the ground biomass thus increasing the risk of fire incidence in a subsequent year, when the intensity of fire would be much more and when the detriment to the ecosystem would be much more. In many parts of the world therefore, prescribed early burn is used as a management tool.

What would happen to the species composition if subjected to varying frequencies of fire has been experimented with, in other parts of the world, especially in forests of birch and asper. However, Indian fire ecological research does not seem to have explored the various spatio-temporal properties of forest fire so as to locate points where positive managerial interventions are possible. With respect to the seasonal Moist deciduous forests (MDFs) of Kerala, there are many potential areas of forest-fire research. Utilizing the information on the response of regeneration populations to different vagaries of fire (in terms of intensity and frequency) is one among them.

Natural silvigenesis is dependent on the available seedling population for silvigenesis. Quantitative information on how various life stages of the tree seedling populations and the seedling populations of various species and species groups respond to varying intensities and frequencies of fire is of practical value in the search for potential alternate management strategies. In an area where sapling and pole populations are below the desirable thresholds, the stock of the seedling population is very important. Here, the fire management strategy should give ample importance so as to promote the stand building process.

The objective of this component of the present investigation was to understand vagaries in survival of tree seedling populations across various intensities and frequencies of fire, in the moist deciduous forests of Kerala.

4.2. MATERIALS AND METHODS

Study area

The study was conducted in the seasonal moist deciduous forests (MDFs) of the Trichur Forest Division (10^o 25'-10^o 45' N latitudes and 76^o 05'-76^o 30' E longitudes), Kerala, falling within the Peechi-Vazhani Wildlife Sanctuary. The experimental plots were located in seasonal moist deciduous forest at Channakkad, about 300 msl, located on the southern slopes of Machad hills, and approximately 7 km North of Pattikkad and NH-47 (National Highway).

Climate

The area receives an annual rainfall of 2,600 mm distributed in two monsoonal episodes, the southwest monsoon (2,154 mm) and northeast monsoon (447 mm) and the diurnal temperature ranged between 19.8^o C (January) and 36.7 ^{o} C (March) keeping the relative humidity between 24.3% (February) and 95.3% (July). Further details of the study area are available in Swarupanandan *et al*. (2001).

Composition of the vegetation

An area of approximately 5 ha was used for conducting the experiments. The moist deciduous forests of which the experiments were conducted belonged to the Southern moist mixed deciduous forests according to conventional forest typology (Champion and Seth, 1968).

In all, the tree vegetation was composed of 33 species organized in three storeys. The top storey composed of species like *Albizia odoratissima, Alstonia scholaris, Bombax ceiba, Dalbergia latifolia, Grewia tiliifolia, Haldina cordifolia, Lagerstroemia microcarpa, Miliusa tomentosa, Pterocarpus marsupium, Tectona grandis, Terminalia* *crenulata, T. bellirica* and *Xylia xylocarpa.* The second storey consisted of *Bridelia squamosa, Cassia fistula, Gmelina arborea* and *Sterculia urens*, and the under storey of *Holarrhena pubescens, Naringi crenulata, Wrightia tinctoria, etc*.

According to the dominance parameters, six species, *viz., Grewia tiliifolia, Xylia xylocarpa, Dillenia pentagyna, Lagerstroemia microcarpa, Bombax ceiba* and *Terminalia paniculata*, constituted over 75 % of the importance value. Among the five species, *Xylia xylocarpa* was the most dominant and *Grewia tiliifolia*, the least.

Further details of the structure and related aspects of regeneration of the moist deciduous forests of the type mentioned above, coming from an area 15 km from the current study area, are to be found in another research report by KFRI (Swarupanandan and Sasidharan, 1992).

Controlled burning experiments

Response of tree seedling populations was studied in a series of experimental plots subjected to burning and fire-exclusion control plots were also studied to understand the difference. Two sets of experiments were carried out to understand the effect of: (1) different intensities of fire, and (b) different frequencies of fire, on tree seedling populations.

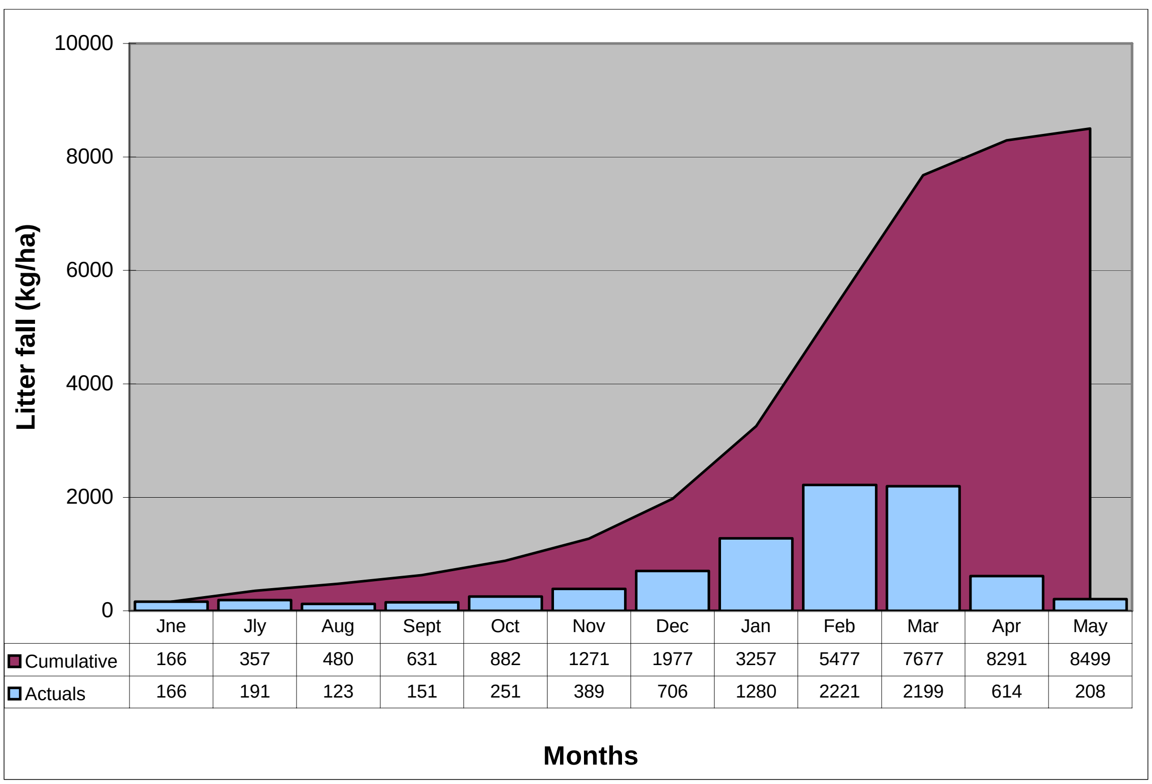
Proxied fire intensity treatments

Response of plants to fire varies with respect to both the intensity and frequency of fire. Intensity refers to the heat generated during fire. In the present study, rather than measuring the intensity of fire in terms of energy released, convenient proxies are used. It is presumed that heat generated is roughly proportionate to the biomass burnt. In MDFs, where only ground fire is prevalent and where fire devours largely the dead biomass on the ground plus the shrubby growth, the fuel load on the ground can be used as a proxy for fire intensity.

In South Indian MDFs in Kerala, litter fall is episodic being largely concentrated during the dry months, November to March. With the onset of the cool weather (November-January) litter fall gets accelerated and the trend extends up to March. Although the peak months of litter fall are January, February and March, the accumulating (cumulative) litter load on the ground is very high from December onwards. It is well over 2000 kg/ha in December and goes on increasing until June, when the SW monsoon strikes Kerala (Figs. 1, 2).

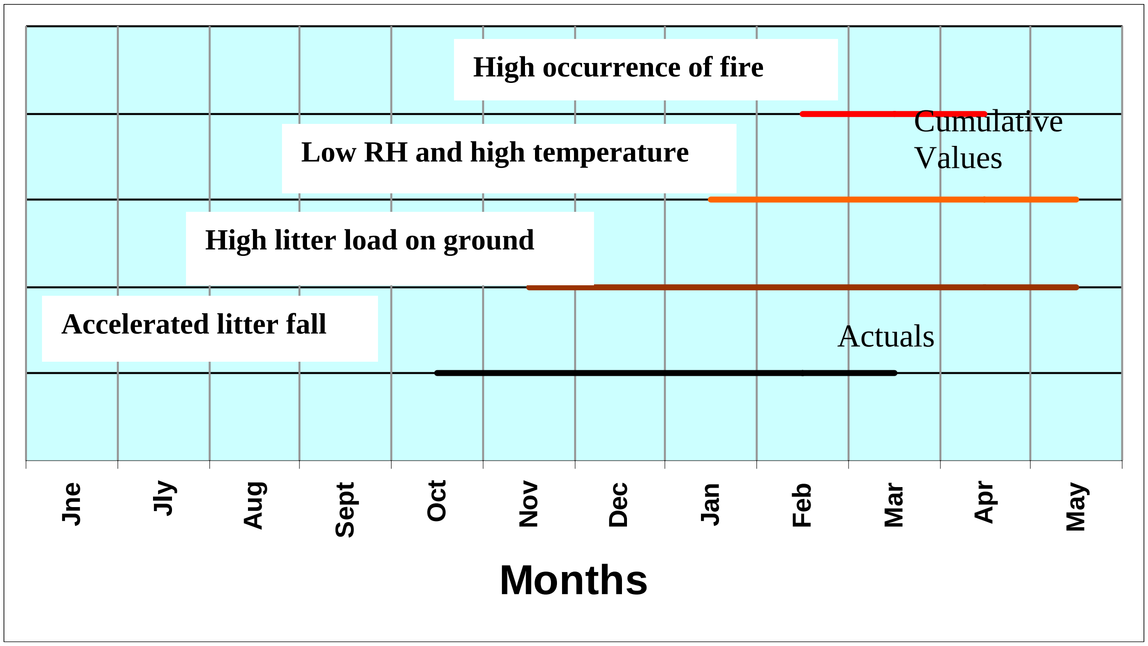
From November onwards, cool weather prevails until the end of January and because of the higher moisture content of the litter, forest fire does not occur during this period, except in erratically dry years. Then onwards till the onset of SW monsoon (June) the sun starts raising the atmospheric temperature and desiccates the litter load making it amenable for fire. Occasional pre-monsoon showers are characteristic of May and the consequent enhancement of the moisture content of the litter prevents the occurrence of fire. As a matter of fact, February, March and April are three months of high occurrence of fire.

Fig.1. Pattern of litter fall in the moist deciduous forest (Swarupanandan *et al*. 2001).



	Jne	Jly	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Cumulative	166	357	480	631	882	1271	1977	3257	5477	7677	8291	8499
Actuals	166	191	123	151	251	389	706	1280	2221	2199	614	208

Fig. 2. Various preconditions for the occurrence of forest fire in moist deciduous forests.



The cumulative litter loads on the ground for a typical MDF in Kerala for the months February, March and April have been computed from Swarupanandan *et al.* (2001; see Fig. 1); the respective values were 5,477 kg/ha (February), and 7,677 kg/ha (March), 8291 kg/ha (April). Considering the time lapse involved across the fires during these months, they have been designated as *Early burn* (February), *Mid burn* (March), and *Late burn* (April), respectively. On the positive relationship between advancing intense-litter-load-months and differing fire intensities, early mid and late burns are proxied for low (February), medium (March) and high intensity (April) fires. Details of the experimental plots used for studying the effect of different intensities of fire are given in Table 1.

Fire frequency treatments

Fire frequency refers to the number of fire episodes with respect to a given site over a period of time. Different fire frequency patterns exist; for example, once in a year, once in two years, once in three years, or twice in a year, and so on. Different fire frequency patterns interplay with differing fire intensities, thus making the fire regime of sites highly varied.

Studying the effect of different fire frequencies on vegetation is as exacting as time consuming. As a matter of fact, in this study, we have attempted to study the impact of fire after single fire-episode (once in a year) and after two fire episodes (once in a year for two consecutive years). We could not study the effect of 3 consecutive fire incidences (spreading over three years) owing to some erratic pre-monsoon showers that mutilated the experimental conditions.

Table1. Details of the experimental plots used for studying response of seedling populations to different fire intensities.

No.	Treatment	Fire intensity	Time of burning	Year of burning	Plot size	Repli-cates	Plots
1	Control	…	Not burnt	Not burnt	0.25 ha	3 plots	T1R1 T1R2 T1R3
2	Early burn	Low	February (2/3 week)	1997	0.25 ha	3 plots	T6R1 T6R2 T6R3
3	Mid burn	Medium	March (2/3 week)	1997	0.25 ha	3 plots	T5R1 T5R2 T5R3

The effect of two consecutive fire episodes (once in a year for two years) was studied in the same experimental plots as indicated in table 1. The two experimental situations provided six sets of data, as given in Table 2.

Table 2. Data sets used for studying response of seedling populations to different fire frequencies.

No.	Burning Treatment	Fire intensity	1st fire episode	Data after 1st fire episode	2nd fire episode	Data after 2nd fire episode
1	Control	…	Not burnt	**T1R1-1** **T1R2-1** **T1R3-1**	Not burnt	**T1R1-2** **T1R2-2** **T1R3-2**
2	Early burn	Low	Feb. 1997	**T6R1-1** **T6R2-1** **T6R3-1**	Feb. 1998	**T6R1-2** **T6R2-2** **T6R3-2**
3	Mid burn	Medium	Mar. 1997	**T5R1-1** **T5R2-1** **T5R3-1**	Mar. 1998	**T5R1-2** **T5R2-2** **T5R3-2**

Parameters and measurements

The effect of fire on vegetation was studied by observing the plants before and after the experimental plots were subjected to prescribed burning as detailed in Table 1. In each of the plots, all trees and their regeneration were enumerated twice, pre-fire and post-fire. Re-identification of the regeneration populations after the fire was made possible by numbered aluminium tags tied to them prior to fire. The pre-fire enumerations recorded height/girth of regeneration populations, and girth in respect of trees >= 3 cm gbh. All missing numbers in the post-fire enumerations were treated as mortality.

The pre-fire enumerations were conducted plus or minus 15-20 days before fire. However, the post-fire enumerations were not conducted immediately after the prescribed burning. Instead, it was done after the initial lapse of the monsoon that followed the summer, during which the prescribed burning was applied. Fire devoured foliage and twigs of much of the regeneration population, and verifying the survival of the individuals, in a great majority of them, was possible only when they start flushing/regenerating in the succeeding monsoon. The delayed post-fire enumeration was therefore to tackle this problem. Regeneration populations displayed different response to fire, as detailed in Table 3.

Table 3. Different regeneration strategies exhibited by regeneration populations.

No.	Physical expression of the response syndrome	Response type	Life forms showing the syndrome
1	Death of whole plant; no part regenerating	Response type-1	Un-established seedlings
2	Death of entire shoot; regenerating from ligneous rootstock	Response type 2	Established seedlings
3	Death of tender twigs only; regenerating from older live branches	Response type-3	Advanced seedlings

***Analysis of data*.**

In the present study only the data pertaining to tree regeneration alone have been analysed and with respect to the survival only.

Abbreviations

For the sake of brevity, the following notations and abbreviations are used in the subsequent text.

DC	- DBH class
DSC	- DBH subclass
MSP	- Mean survival percentage
MSP_C	- Mean survival percentage for Control treatment (unburnt samples), where the subscript ‘$_C$ ‘denotes ‘Control’.
MSP_{EB}	- Mean survival percentage for Early burn treatment), where the subscripts ‘$_{EB}$ ‘denote ‘Early burn’.
MSP_{MB}	- Mean survival percentage for Mid burn treatment), where the subscripts ‘$_{MB}$ ‘denote ‘Mid burn’.
MSPs	- Mean survival percentage(s)
N	- Number of stems
S	- Species number
SC	- Size class
SCs	- Size class(s)
SSC	- Size subclass
SSCs	- Size subclass(s)

4.3. RESULTS

The results are arranged mainly under two main sections: survival of species number (S) and survival of stems (N) under differing intensities of fire and differing frequencies of fire.

Changes in species number (S) in response to differing intensities of fire

At 1-10 cm dbh level: Before fire, the number of tree species (S) in the three experimental treatments ranged between 41 and 52. The data presented in Table 4 shows that the mean survival percentages (MSPs) across the three treatments were high for all the treatments. As expected across the values the Control samples (unburnt) showed the highest MSP (98.7 ± 1.16), the Early burn treatment received a lower percentage (88.7 ± 11.61) and the Mid burn treatment the least (70.0 ± 2.38). The difference in the MSP between Early burn and Mid burn is understandable, as fire intensity is higher in the Mid burn treatment.

Table 4. Tree species (S) survival in response to burning treatments (class 1-10 cm dbh).

Treatments	Replicates	Species before fire	Species after fire	Survival %	Mean ± SD
Control	T1R1	52	51	98.1	98.7 ± 1.16
	T1R2	48	47	97.9	
	T1R3	41	41	100.0	
Early burn	T6R1	45	44	97.8	88.7 ± 11.61
	T6R2	41	38	92.7	
	T6R3	41	31	75.6	
Mid burn	T5R1	41	28	68.3	70.0 ± 2.38
	T5R2	44	32	72.7	
	T5R3	42	29	69.1	

The life stage 1-10 cm dbh, as a class although is fairly comparable to higher classes like 10-20 cm dbh class (DC), 20-30 cm dbh class. Nevertheless, survival in the lower sectors of this class is most important form the point of view of establishment, and for this reason, the data were further compartmented and analysed to know the differences. Accordingly, survival was evaluated in the following dbh subclasses (DSC): 1-2.5 cm, 2.5-5 cm, 5-7.5 cm, and 7.5-10 cm. The results are presented below.

At 1-2.5 cm dbh level: The MSP for the 1-2.5 cm DSC of tree regeneration followed the same pattern as shown by the 1-10 cm DC: MSP_C > MSP_{EB} > MSP_{MB} (Table 5). Nevertheless, the MSP_{EB} for the 1-2.5 cm DSC (77.7 $\pm$ 20.08) was lower than the aggregate MSP_{EB} for the 1-10 cm DC and the MSP_{MB} for the 1-2.5 cm (46.7 $\pm$ 6.04) DSC was much lower to the MSP_{MB} for the 1-10 cm DC (70.0 $\pm$ 2.38). This infers that the MSPs in the lower sub size classes (SSCs) of regeneration is lower than the MSP of the aggregate value for the SC, which however gets masked in the aggregate MSPs.

Table 5. Tree species (S) survival in response to burning treatments (class 1-2.5 cm dbh).

Treatments	Replicates	Species before fire	Species after fire	Survival %	Mean $\pm$ SD
Control	T1R1	34	34	100.0	99.2 $\pm$ 1.44
	T1R2	40	39	97.5	
	T1R3	34	34	100.0	
Early burn	T6R1	33	30	90.9	77.7 $\pm$ 20.08
	T6R2	32	28	87.5	
	T6R3	33	18	54.5	
Mid burn	T5R1	29	15	51.7	46.7 $\pm$ 6.04
	T5R2	35	14	40.0	
	T5R3	31	15	48.4	

At 2.5-5 cm dbh level: Here again, the general trend MSP_C > MSP_{EB} > MSP_{MB} holds true across the treatments; this SSC however being higher than the 1-2.5 cm SSC, the MSP_{EB} for 2.5-5 cm DSC (95. 1 ± 2.19) is definitely higher than the MSP_{EB} for 1-2.5 cm SSC (77.7 ± 20.08) (Table 6). Following the same trend, MSP_{MB} for 2.5-5 cm DSC (87.2 ± 7.13) is definitely higher than the MSP_{MB} for 1-2.5 cm SSC (46.7 ± 6.04).

Table 6. Tree species survival in response to burning treatments (class 2.5-5 cm dbh).

Treatments	**Replicates**	**Species before fire**	**Species after fire**	**Survival %**	**Mean ± SD**
Control	T1R1	24	22	91.7	97.2 ± 4.81
	T1R2	30	30	100.0	
	T1R3	24	24	100.0	
Early burn	T6R1	30	29	96.7	95. 1 ± 2.19
	T6R2	25	24	96.0	
	T6R3	27	25	92.6	
Mid burn	T5R1	19	15	78.9	87.2 ± 7.13
	T5R2	24	22	91.7	
	T5R3	22	20	90.9	

At 5-7.5 cm and 7.5-10 cm DSC levels: The MSPs in these higher SSCs are very high, irrespective of the treatments and reaches closer to 100% or slightly lower to it (Tables 7, 8). As the size of plant increases, the MSP also increases; so the mortality to fire is largely clustered to the lower SSCs of the tree regeneration.

Table 7. Tree species (S) survival in response to burning treatments (class 5-7.5 cm dbh).

Treatments	Replicates	Species before fire	Species after fire	Survival %	Mean ± SD
Control	T1R1	12	11	91.7	97.2 ± 4.80
	T1R2	12	12	100.0	
	T1R3	14	14	100.0	
Early burn	T6R1	17	17	100.0	100.0 ± 0.00
	T6R2	18	18	100.0	
	T6R3	13	13	100.0	
Mid burn	T5R1	15	15	100.0	97.8 ± 3.85
	T5R2	16	16	100.0	
	T5R3	15	14	93.3	

Table 8. Tree species survival in response to burning treatments (class 7.5-10 cm dbh).

Treatments	Replicates	Species before fire	Species after fire	Survival %	Mean ± SD
Control	T1R1	7	7	100.0	100.0 ± 0.00
	T1R2	3	3	100.0	
	T1R3	4	4	100.0	
Early burn	T6R1	5	5	100.0	100.0 ± 0.00
	T6R2	8	8	100.0	
	T6R3	6	6	100.0	
Mid burn	T5R1	9	8	88.9	96.3 ± 6.42
	T5R2	8	8	100.0	
	T5R3	6	6	100.0	

Changes in density (N) in response to differing intensities of fire

At 1-10 cm dbh class level: The total number of stems (N) The mean survival percentages of the stems (N) also displayed the same trend as displayed by the species number (S): $MSP_C > MSP_{EB} > MSP_{MB.}$ The aggregate MSP for the 1-10 cm DC (MSP_C) was 70.7 ± 5.44 and the same figure was displayed by the Early burn treatment (MSP_{EB}), but the MSP_{MB} was very low compared to these figures (47.3 ± 7.11) (Table 9). This difference is much more drastic than in the case of species number (S). Fire intensity therefore is an important parameter, and more than impoverishing the species composition, it affects the population structure badly by diminishing the stocking drastically

Table 9. Tree stem (N) survival in response to burning treatments (class 1-10 cm dbh).

Treatments	Replicates	Stems before fire	Stems after fire	Survival %	Mean ± SD
Control	T1R1	1065	887	83.3	70.7 ± 5.44
	T1R2	1128	1041	92.3	
	T1R3	940	875	93.1	
Early Burn	T6R1	1065	887	83.3	70.7 ± 17.46
	T6R2	1307	1019	78.0	
	T6R3	1407	712	50.8	
Mid Burn	T5R1	867	440	50.8	
	T5R2	1073	420	39.1	47.3 ± 7.11
	T5R3	995	518	52.1	

At 1-2.5 cm dbh class level: The compartmented MSP for the DSC 1-2.5 cm is still more interesting. While the Control still displayed MSPs closer to 100% (92.3 ± 0.99), the MSP_{EB} (57.0 ± 23.10) and MSP_{MB} (19.8 ± 4.53) were quite low, compared to their corresponding values for the aggregate DSC 1-10 cm: MSP_{EB} (70.7 ± 17.46) and MSP_{MB} (47.3 ± 7.11). Here, it is to be noted that MSP_{MB} (19.8 ± 4.53) is only one third of the MSP_{EB} (57.0 ± 23.10) (Table 10).

Table 10. Tree stem (N) survival in response to burning treatments (class 1-2.5 cm dbh).

Treatments	Replicates	Stems before fire	Stems after fire	Survival %	Mean ± SD
Control	T1R1	566	526	92.9	92.3 ± 0.99
	T1R2	634	578	91.2	
	T1R3	475	441	92.8	
Early Burn	T6R1	610	442	72.5	57.0 ± 23.10
	T6R2	753	513	68.1	
	T6R3	916	279	30.5	
Mid Burn	T5R1	442	88	19.9	19.8 ± 4.53
	T5R2	695	106	15.3	
	T5R3	514	125	24.3	

At 2.5-5 cm, 5-7.5 cm and 7.5-10 cm DC levels: There is no drastic difference between the MSPs of the various treatments Control, Early Burn and Mid burn, except the Mid burn treatment, the values being closer to 100%, except for the 2.5-5 cm DSC (79.9 ± 0.74) (Tables 11-13).

Table 11. Tree stem (N) survival in response to burning treatments (class 2.5-5 cm dbh).

Treatments	Replicates	Stems before fire	Stems after fire	Survival %	Mean ± SD
Control	T1R1	278	255	91.7	95.3 ± 4.28
	T1R2	421	396	94.1	
	T1R3	374	347	100.0	
Early Burn	T6R1	349	342	98.0	92.1 ± 5.42
	T6R2	474	431	90.9	
	T6R3	426	372	87.3	
Mid Burn	T5R1	340	272	80.0	79.9 ± 0.74
	T5R2	310	250	80.6	
	T5R3	403	319	79.2	

Table 12. Tree stem (N) survival in response to burning treatments (class 5-7.5 cm dbh).

Treatments	Replicates	Stems before fire	Stems after fire	Survival %	Mean ± SD
Control	T1R1	86	82	95.4	94.8 ± 2.83
	T1R2	60	55	91.7	
	T1R3	72	70	97.2	
Early Burn	T6R1	96	94	97.9	97.8 ± 2.14
	T6R2	70	67	95.7	
	T6R3	53	53	100.0	
Mid Burn	T5R1	71	69	97.2	96.7 ± 2.08
	T5R2	50	49	98.4	
	T5R3	71	67	94.4	

Table 13. Tree stem (N) survival in response to burning treatments (class 7.5-10 cm dbh).

Treatments	Replicates	Stems before fire	Stems after fire	Survival %	Mean ± SD
Control	T1R1	10	10	100.0	96.7 ± 5.77
	T1R2	4	4	100.0	
	T1R3	10	9	90.0	
Early Burn	T6R1	6	6	100.0	100.0 ± 0.00
	T6R2	8	8	100.0	
	T6R3	8	8	100.0	
Mid Burn	T5R1	12	11	91.7	97.2 ± 4.81
	T5R2	13	13	100.0	
	T5R3	7	7	100.0	

Changes in species number (S)

At 1-10 cm dbh level in response to differing frequencies of fire: Changes in MSP both of S and N, in response to differing frequencies of fire have been analysed only at the aggregate DC 1-10 cm. Table 14 provides MSPs for the three treatments, after the 1st year burning and after 2 consecutive years of burning. While the values for the control (unburnt) treatment remained closer to 100%, all the values after the 2nd year burning were lower than the corresponding values after the 1st year burning. In these treatments also, the general relationship $MSP_{C} > MSP_{EB} > MSP_{MB}$ was found to hold true.

Table 14. Species survived after 1st-yr and 2nd-yr fire (class 1-10 cm dbh)

Treatments	**Replicates**	**S1**	**S2**	**S3**	**S1 %**	**S2 %**	**S3 %**	**S2 x $\pm$ SD**	**S3 x $\pm$ SD**
Control	T1R1	47	47	46	100	100	97.9	99.3 $\pm$ 1.21	98.6 $\pm$ 1.21
	T1R2	47	46	46	100	97.9	97.9		
	T1R3	41	41	41	100	100	100		
Early burn	T6R1	45	44	40	100	97.8	88.9	88.7 $\pm$ 11.63	77.6 $\pm$ 10.44
	T6R2	41	38	31	100	92.7	75.6		
	T6R3	41	31	28	100	75.6	68.3		
Mid burn	T5R1	41	30	25	100	73.2	61	72.4 $\pm$ 1.44	67.5 $\pm$ 5.60
	T5R2	41	29	29	100	70.7	70.7		
	T5R3	41	30	29	100	73.2	70.7		

SD- standard deviation. S1, S2 and S3 are species number (S) at the time of first enumeration (pre-fire), second enumeration (post first-year burning), and third enumeration (post second-year burning). X- arithmetic mean.

Changes in density (N)

At 1-10 cm dbh level, in response to differing frequencies of fire: Following the same trend as exhibited by the MSPs of species number, the stem density also the same pattern, but with a striking difference; the values after the 2nd year fire incidence is very low compared to that after the first year burning. Here again, this shows that a high fire frequency is definitely contributing to the seedling impoverishment, much more drastically than the fire intensity (Table 15).

Table 15. Stems survived after 1st-yr and 2nd-yr fire (class 1-10 cm dbh)

Treatments	Replicates	N1	N2	N3	N1 (%)	N2 (%)	N3 (%)	N2% x +SD	N3% x +SD
Control	T1R1	940	873	760	100	92.9	80.9	92.8 ± 0.42	81.3 ± 0.81
	T1R2	1119	1033	903	100	92.3	80.7		
	T1R3	931	867	765	100	93.1	82.2		
Early burn	T6R1	1061	884	657	100	83.3	61.9	70.7 ± 17.51	40.1 ± 18.89
	T6R2	1305	1019	387	100	78.1	29.7		
	T6R3	1403	712	402	100	50.7	28.7		
Mid burn	T5R1	862	440	297	100	51	34.5	47.6 ± 6.99	36.5 ± 6.63
	T5R2	1053	417	327	100	39.6	31.1		
	T5R3	990	518	435	100	52.3	43.9		

SD- standard deviation. N1, N2 and N3 are number of stems (N) at the time of first enumeration (pre-fire), second enumeration (post first-year burning), and third enumeration (post second-year burning). X – arithmetic mean.

4.4. DISCUSSION AND CONCLUSIONS

For comparison of the results from the two sets of experiments, the tabular data have been summarized in figs. 3 and 4. The findings in terms of the MSPs in relation to the species number (S) are summarized in fig. 3 and those in terms of the stem density (N), in fig. 4. The results make out the following.

Tree seedling populations show increasing MSPs, with increasing life stages, with respect to fire and that higher fire intensity (late burns, in April) and higher fire frequencies are much more detrimental to the regeneration populations, in terms of their survival. This is quite expectable, as the total quantity of energy released in to the ecosystem at higher fire intensities and frequencies is quite compared to their lower levels. It is also evident that, the survival is worst affected by the lower SSCs of the regeneration and would logically conclude to the need for higher measures of protection in augmented planted areas for 1-3 years after planting. The same would also be required of stands wehre regeneration populations are quite thin.

Systematic fire ecological research of the moist deciduous forest ecosystem would yield very valuable low-risk fire management strategies that make sense in the economic sense too. In addition to the potentials of exploring the survival behavior of seedling populations to fire, the following are some of the areas that might yield meaningful management strategies.

Planning fire management in tune with erratic climate regimes

Climate of any region exhibits certain vagaries, over spans of time. If the predictable elements of these vagaries could be identified, suitable management strategies could be framed to tackle the situations. For example, if a given year is going to have low rainfall and increasing dryness, intensification of fire management activities during that year would be very apt. Likewise, low fire management investment would be required for a probable high-rainfall low-drought year.

Judicious fire management strategies

The underlying assumption is that not all the area under the MDFs has the same fire incidence probability. Therefore, judicious fire protection measures should be based on observed patterns of spatio-temporal patterns of forest fire occurrence in the forests. Stratification of the forest areas for fire occurrence is the first step for this end.

Judicious use of early prescribed burning as a management tool

A high intensity fire is more damaging to the ecosystem than a low intensity fire. Early prescribed burning of certain critical areas are likely to prevent further spread of fire to vast areas and would minimize the risk due to fire. If such critical areas could be identified, this has financial implications.

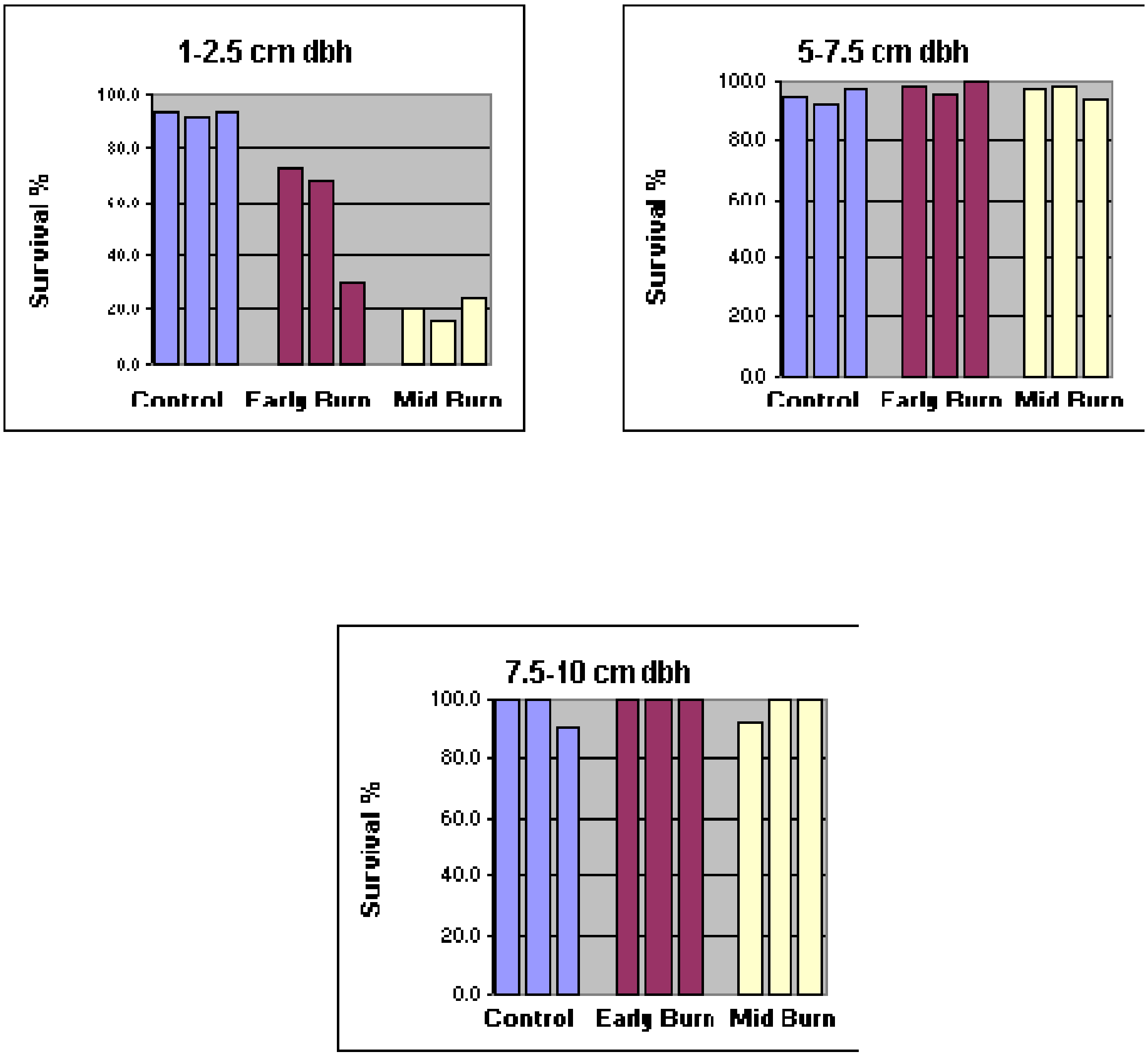


Fig. 3. Mean survival percentages of stems (N) after fire, across different size classes.

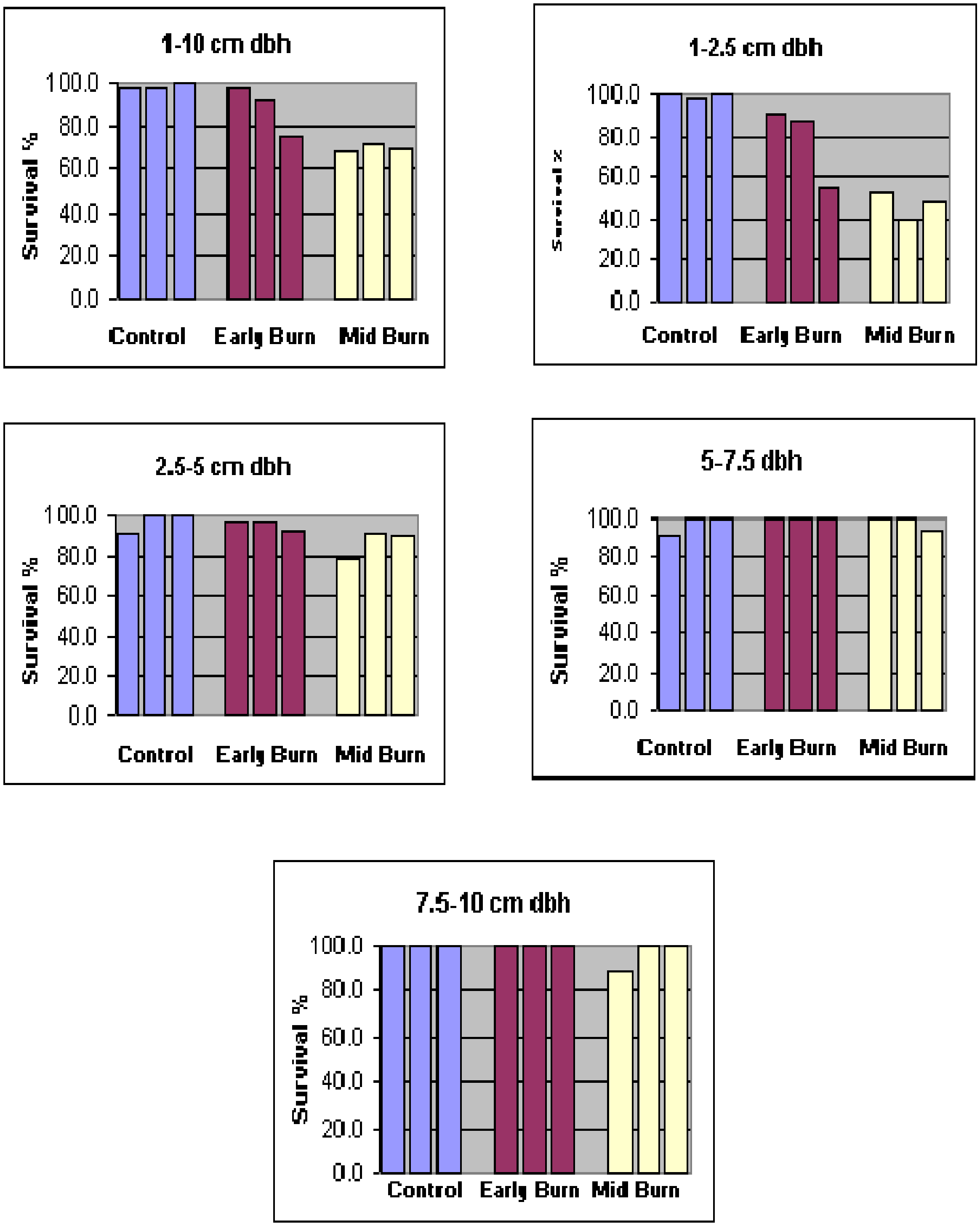


Fig. 4. Mean survival percentages of species (S) after fire, across different size classes.

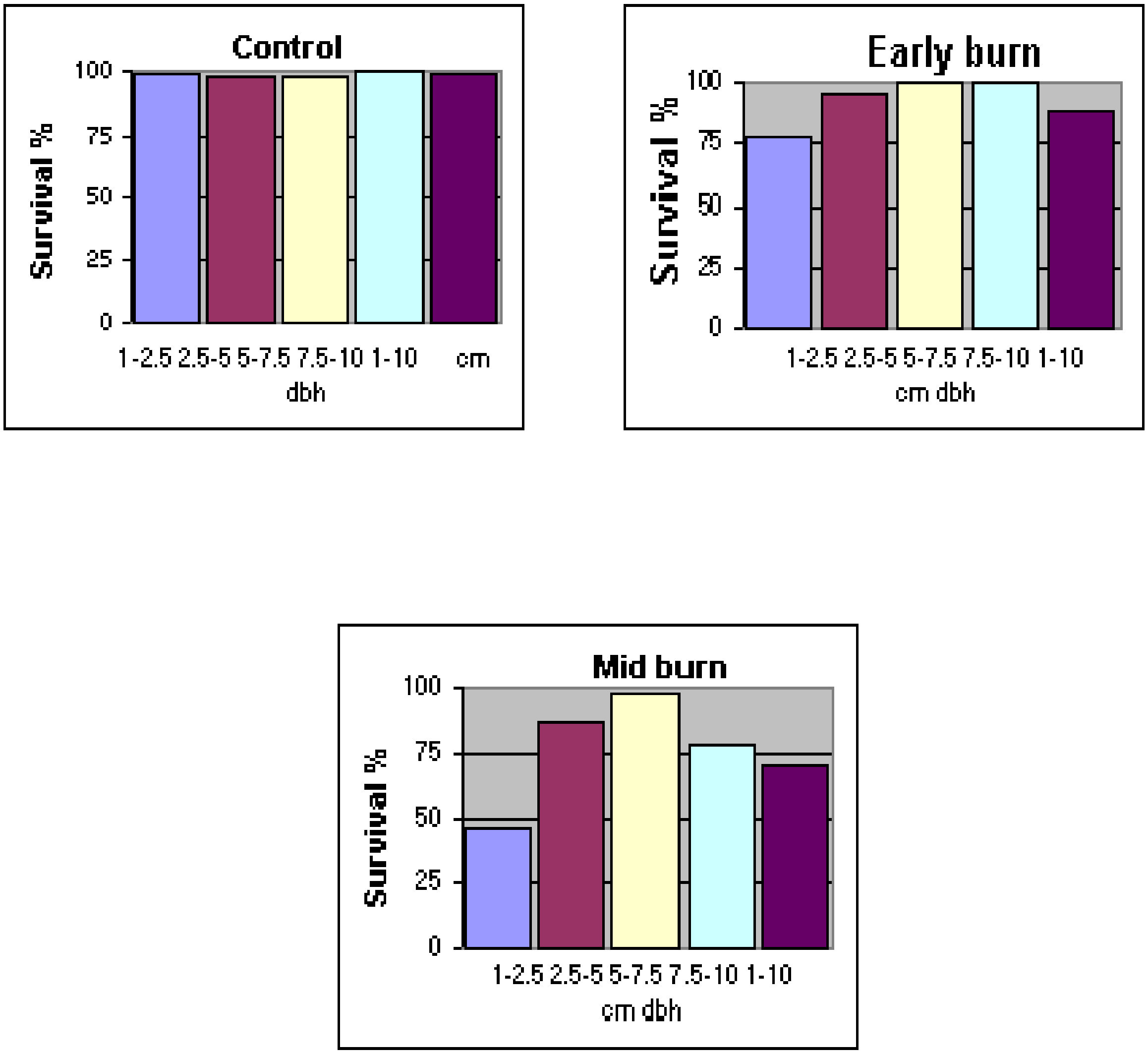


Fig. 5. Mean survival percentages of species number (S) after fire across the various size classes.

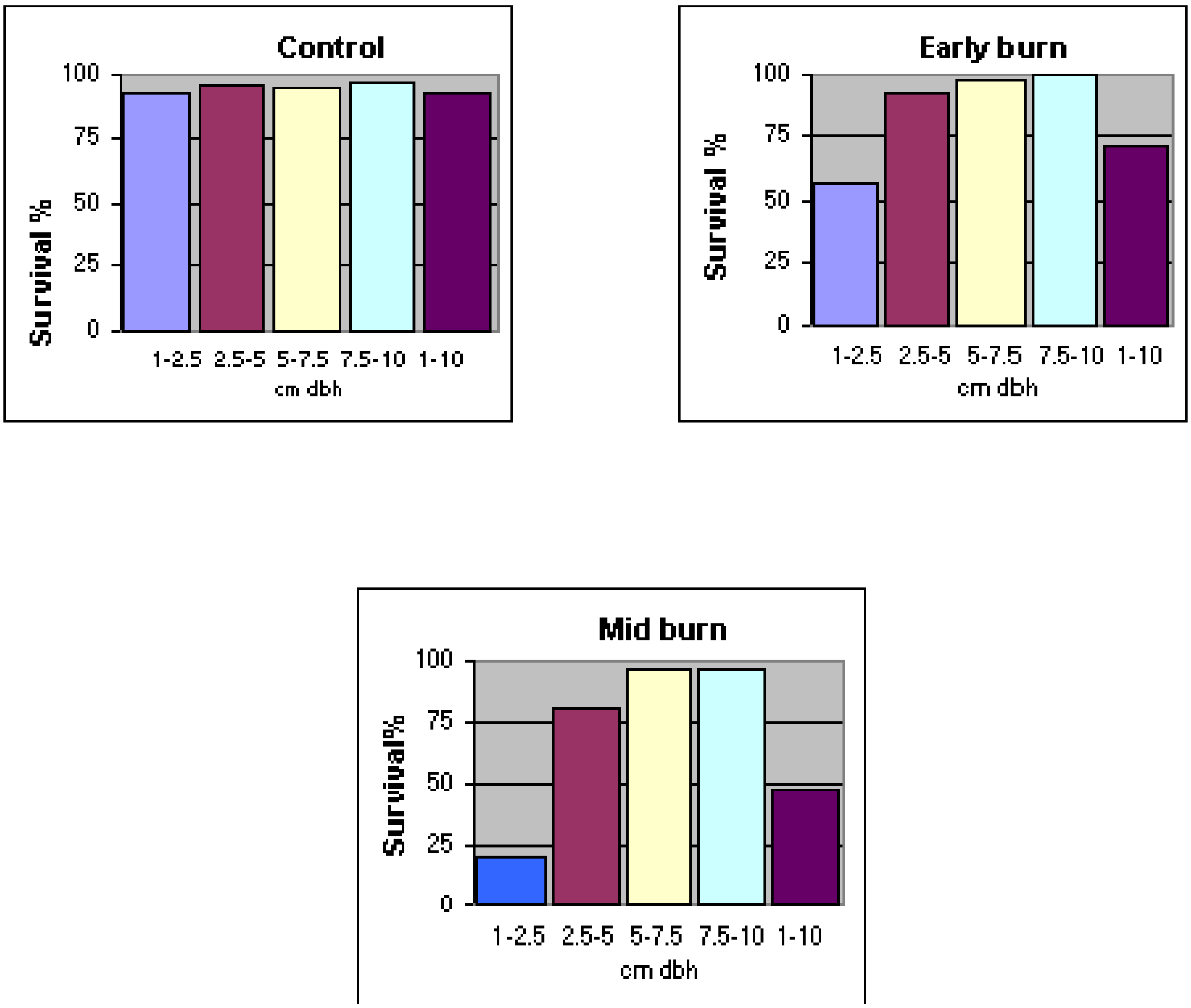


Fig. 6. Mean survival percentages of stems (N) after fire across the various size classes.

5. GENERAL CONCLUSIONS

Forest fires are known to bring in extensive damages to the forests and is a major cause of degradation and desertification of forest areas. However, the problem of fire has never been a subject of serious scientific research in the country. It was in this context the present study was initiated with the objectives to look into some aspects of fire hardiness of moist deciduous species and their ability to regenerate in fire prone areas. The study has elucidated the following conclusions

The surface texture and structure of bark of the MDF species investigated did not show any specific promoting characters for attracting stem surface ignition, except in few rough barked species. Among the species studied *Terminalia crenulata* and *Bombax ceiba* are having thickest bark, while *Lagerstroemia microcarpa* has the thinnest bark.

In general, the thickness of bark increased with the increase in age of the trees, in all the species, and the resistance of fire was also proportionate to the thickness of bark. However, the thickness of bark alone did not contribute much to the fire resistance of species.

The moisture content of the bark in the species studied was found not dependent on the thickness, but rather on the tissue composition and is also found proportionate to the age.

The potential for bark regeneration after a loss due to fire is least in the case of *Dalbergia latifolia* whereas other species are moderate in this respect. These points out the need for more stringent fire control measures in areas where such species occur in increased density.

The bole characteristics, branching pattern, and the canopy structure are found to be advantageous for resisting recurrent surface fires in most of the species.

The growth and fire survival of MDF species studied, when they are planted as stumps revealed that stumps having thicker diameter at their collar region(>2cm) have greater potential in regeneration and show increased vigour of shoots and roots, compared to those having thinner diameter (2m).

Among the species tried, *Gmelina arborea* and *Pterocarpus marsupium* showed better fire survival and regeneration potential compared to others. Since the stumps are having higher survival capacity compared to seedlings they appear to be more suitable to be used in re-vegetation activities especially those in fire prone areas.

The ecological studies carried out, in order to understand the fire survival of MDF species indicated that, the survival is worst affected to the lower SSCs of the seedling regeneration and points out the need for increased fire protection during the initial years. In order to evolve suitable low-risk economically viable fire management programmes, it appears to be highly essential to carry out detailed fire ecological studies for specific forest types.

Establishment of fire prediction mechanism is important prerequisite for the correct environmental assessment for fire management programmes. Since all the MDF species are not equally fire prone, based on the spacio-temporal pattern, steps should be initiated to demarcate regions for judicious fire management strategies. Likewise, judicious prescribed burning should also be practiced to minimise the risk of damage due to high intensity fires.

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