# IMPACT OF ECORESTORATION ON SOIL SEED BANK IN EASTERN ATTAPPADY, KERALA

By

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**(2012-17-105)**

## THESIS

***Submitted in partial fulfilment of the requirement for the degree of***

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## DECLARATION

I hereby declare that the thesis entitled "**Impact of ecorestoration on soil seed bank in Eastern Attappady, Kerala.**" is a bonafide record of research done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis, entitled **"Impact of ecorestoration on soil seed bank in Eastern Attappady, Kerala"** is a record of research work done independently by **Mr. Fredy, C. Timy.** (2012-17-105) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

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We, the undersigned members of the Advisory Committee of **Mr. Fredy, C. Timy. (2012-17-105)** a candidate for the degree of **Master of Science in Forestry** agree that this thesis entitled **"Impact of ecorestoration on soil seed bank in Eastern Attappady, Kerala"** may be submitted by him in partial fulfillment of the requirement for the degree.

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*Dedicated to my parents & teachers*

# Introduction

# 1. INTRODUCTION

Widespread deforestation and declining condition of the world's forests has resulted in environmentally, economically and aesthetically impoverished landscapes. Recent reviews indicate that the rate of deforestation is slowing in some countries, while the overall rate of forest loss remains high and estimated at around 130,000 $km^2$/year during the decade 2000-2010 (FAO, 2010). Global climate change, increasing human population growth and urbanization represent increasing pressures on biodiversity and ecosystem function. In response to forest loss and degradation, increasing efforts are being directed towards ecological restoration. It is now widely recognized that conservation of existing natural fragments will not be sufficient to maintain extant biodiversity or meet conservation goals. In such a situation ecological restoration has been initiated as a main alternative to safeguard natural resources and to conserve biodiversity.

Ecological restoration refers to the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (Mansourian, 2005). The purpose of restoration is the comprehensive recreation of a specified historical ecosystem, including structural, compositional, and functional aspects, which were prevalent prior to degradation. Ecological restoration is a relatively new science, and thus requires more research in order to understand its complexities and to create better outcomes for biodiversity conservation in future. Goal of a restoration project is to create an ecosystem that is self-supporting and resilient to perturbation. However, restoration is a long term process and the success of its methods is often hard to assess. Monitoring is an important phase of ecological restoration. Monitoring evaluates richness, composition and biomass of planted and regenerating individuals in a restored site. Soil seed bank is considered as one of the tools of ecological restoration monitoring.

Seed bank is defined as the reserves of viable seed present in and on the soil surface and associated litter, capable of replacing adult plants (Simpson *et al.*, 1989). Soil seed bank research have important role in restoration, renovation, biodiversity preservation, vegetation succession, diffusion processes and other aspects. Seed banks are important in maintaining species and genetic diversity in communities and in allowing species to persist through disturbance or adverse conditions. Generally resident plant communities reflect the size, composition and distribution of seed bank. Apart from this, seed from distant sources also contribute to seed bank. The seed bank is a useful indicator of the potential species composition at a site. Knowing the seed bank composition and distribution it can contribute to the historical and predictive understanding of plant community composition, determining probable species composition following a disturbance and predicting the potential contribution of the seed bank for the restoration of a target plant community. The composition and recruitment pattern of seeds in the soil seed bank may offer information on species that have the potential to germinate in rehabilitated sites following a disturbance. This knowledge is useful to predict future successional patterns within rehabilitated sites.

Attappady is located in the North eastern part of Palakkad district, in the Western Ghats region of Kerala, the area has historically experienced severe ecological degradation. The progressive loss of soil, water and vegetation resulted in the expansion of wastelands. It was in these circumstances that the Attappady Wasteland Comprehensive Environmental Conservation Project (AWCECOP) was taken up in 1996 with the objective of halting the processes of ecological and social degradations and improving the livelihood base of the tribal communities. The AWCECOP aims at eco-restoration and promotion of sustainable livelihoods using participatory resource management methodology. The major objectives of this project include ecological restoration of Attappady, prevention of further ecological degradation, development of replicable models of participatory eco-restoration and promotion of sustainable livelihood options for the local people in harmony with the resource base. The project was implemented by Attappady Hills Area Development Society (AHADS), an autonomous institution under the Local Self Government Department of Government of Kerala.

The objective of present study aims to understand the impact of ecorestoration on soil seed bank in Eastern Attappady and relate it to the structural attributes of vegetation present in the area.

# Review of Literature

# 2. REVIEW OF LITERATURE

Tropical forests have long been exploited and degraded by humans. It is estimated that around 30% of global forest land has been completely cleared and 20% has been degraded. In a world of rapid human population growth, development and environmental degradation, ecological restoration is a vital process to recreate, establish and accelerate natural successional processes. Soil seed bank is considered as one of the tool of ecological restoration management.

Soil seed bank plays an important role in plant ecology research, also it is one of the hot research topics in plant population ecology and vegetation ecology. It provides essential information on status and regeneration potential of ecorestored area. Soil seed bank research started earlier and literature available are limited especially with respect to tropical situation. This section reviews various studies that form the foundation for the present investigation.

## 2.1. SOIL SEED BANK

### 2.1.1. Definition

Seed banks represent a sum of reproducible structures such as seed, fruit, asexual propagule and other reproducible parts of the plant. According to Roberts (1981), the term soil seed bank has been used to designate the viable seed reservoir present in a soil. For Baker (1989), this reservoir corresponds to the seeds not germinated but, potentially capable of replacing the annual adult plants, which had disappeared by natural death, diseases, disturbances and animal consumption, including man. Simpson *et al.*, 1989 defined soil seed bank as all viable seeds and fruits present on or in the soil and associated litter or humus.

The concept of the seed bank was first identified by Darwin when he observed the emergence of seedlings from pond mud. In 1882, Putersen published first scientific research report on occurrence of seeds at different soil depth (Roberts, 1981). The seed banks of arable weeds and their role in the rapid exploitation of disturbed ground were among the first group of plants to receive intensive study because of its economic importance (Grime, 1981). Later seed bank research extended to non- weedy plants and wide range of other habitats.

Soil seed bank research have important role in restoration, renovation, biodiversity preservation, vegetation succession, diffusion processes and other aspects (Li, 2009). Generally, resident plant community reflect the size, composition and distribution of seed bank, apart from this, seed from distant sources also contribute to seed bank (Simpson *et al.*, 1989).

In 1979, Thompson and Grime recognized two main seed bank strategies: transient types composed of seeds that persist for less than a year and persistent types in which seeds remain viable for longer periods of time. The important distinction is transient seed banks tend to be those that germinate immediately or seasonally, while those that persist for longer periods are dormant until they receive an appropriate trigger (Rokich and Dixon, 2007). Triggers are related to disturbance or opportunity. All species do not contribute equally to the soil seed bank. As a result soil seed banks are highly variable in composition and seed density both locally and globally depending on the ecosystem type, species present and time since disturbance (Hopfensperger, 2007).

Persistent seed bank may function as the genetic memory of a population and play an important role in community dynamics and regeneration. The capacity to perform persistent seed bank allows species to survive episodes of disturbance and destruction. Many species have this capacity and many do not. An understanding of persistent seed bank is the key to many aspects of vegetation management and conservation (Hegazy *et al.*, 2009).

### 2.1.2. Seed Dispersal

Seed producing place may not have the carrying capacity to grow, in such case in order to avoid competition, seeds are dispersed. The process of the development of soil-stored seed bank population dynamics begin when seeds enter an area via the seed rain. Seeds may originate from plants in the immediate area and neighboring area and may be dispersed by water, animals, birds, wind, or gravity (Hall and Swaine, 1980; Quintana-Ascencio *et al.*, 1996; Richards, 1996).

The nature of dispersal implies seeds are not dispersed uniformly. Rather, as distance from the parent plant increases, seed dispersal declines exponentially, which is called a seed shadow (Richards, 1996). Flemming and Heithaus put forward hypothetical relationship between seed dispersal and distance. As distance from a seed source increases, seed density exponentially decreases, and seedling mortality decreases. In addition, Saluei and Swaine (1988) evaluated the seeds of gap dependent species and Howe (1986) found that seeds of pioneer species decreased exponentially as distance from parent increased. Therefore, areas close to seed sources will have a larger number of seeds and species than areas more distant from seed sources.

Generally, soil seed banks were dominated by herbaceous species, this could be attributed to easy dispersal ability of herbaceous species by various dispersal agents such as wind and water because of their light weight. Given that many herbs and shrubs have small-sized seeds, they tend to produce seeds in large quantities and end up dominating the soil seed bank (Obiri *et al.*, 2005). These results concur with Liu *et al.* (2009) and Oke *et al.* (2006), whose findings indicated that herbaceous species dominated the soil seed banks, while only a few tree species were capable of accumulating long-lived seeds in the soil. Most of the tree species seeds are large, hence more vulnerable to predation than small seeds.

### 2.1.3 Seed dormancy and germination

Dispersed seed generally show a period of rest termed dormancy (Harper, 1977). Seeds may be integrated into the soil seed bank by animals such as rodents and worms, or by physical processes such as wind, rain, and erosion (Richards, 1996). Once a seed is incorporated into the dormant seed bank it may follow one of two pathways: death by decay and senescence, or is stimulated to become a component of the active seed bank. Prior to stimuli, seeds remain in a dormant state.

Three major types of dormancy effect seed germination: innate, induced, and enforced dormancy (Harper, 1977). Innate dormancy state prevents seeds from germinating while connected to the parent plant. Induced dormancy occurs when the seed has changed its dormancy state because of an environmental condition, such as drought or carbon dioxide increase. Enforced dormancy is maintained by absence of germination requirements, such as moisture, oxygen, or light (MacKay, 1972; Harper, 1977; Rees, 1997). Light also affects germination; red light promotes germination and blue light inhibits germination (Mayer and Poljakoff-Mayber, 1989). Once dormancy is broken, seeds become incorporated into the active seed bank, where seeds germinate to become seedlings. Bossuyt and Hermy (2003) studied the regeneration of ancient forests in Belgium and discovered the ancient forest species mostly reproduce vegetatively or by transient seeds.

Several internal and external factors prevent seeds from germination. Among the internal factors, some important factors are: the presence of a seed coat, which is a barrier to the penetration of water and oxygen; presence of a biochemical inhibitor in the seed; and immature embryo. Among the external factors, the most common are soil water content and temperature (Fernández-Quintanilla *et al.*, 1991).

### 2.1.4. Dormant and active seed bank

All the seeds do not germinate as soon as they dispersed. Factors that affect seed germination are dormancy type and triggers required to initiate seed germination. In 1987, Hopkins and Graham studied dormancy in tropical plant species of Australia, and showed that some seeds of pioneer species remained viable in the soil for up to two years, compared to late successional species that remained viable for six weeks or less. In addition, Holthuijzen and Boerboom (1982) tested for seed viability of the pioneer/light demanding genus *Cecropia* (Cecropiaceae) in Surinam by burying seeds of two species in earthenware pots. These two species remained viable up to 62 months. Lastly, three gap dependent species in Costa Rica, *Phytolacca rivinoides* (Phytolaccaceae), *Witheringia solanacea* (Solanaceae), and *W. coccoloboides* (Solanaceae), were able to remain viable in the soil seed bank up to 27 months (Murray, 1988).

Seeds that have the ability to remain viable in the soil until suitable germination conditions arise are a component of the dormant (persistent) seed bank (Harper, 1977; Cook, 1980; Garwood, 1989). Generally, these species also exhibit a suite of life history traits that include: they are short-lived, fast growing, wind-dispersed seeds that fruit every year or continuously throughout the year, and have a steep dispersal curve, weak competitive ability, and low decay rates of seed population in soil (Harper, 1977; Cook, 1980; Hall and Swaine, 1980; Whitmore, 1990). In contrast, non-dormant, short-lived seeds that germinate shortly after arrival in the seed bank are a component of the active (transient) seed bank (Harper, 1977; Garwood, 1989). These seeds usually form seedling banks rather than seed banks. The life history traits of these species include: large seeds and fruits, long-lived plants, low relative growth rate, strong competitive ability, high decay rates of seed populations in soil, and flat dispersal curve (Cook, 1980). They have irregular fruiting patterns and may fruit every three to seven years (Putz and Appanah, 1987). Some of these species include climax species such as *Syzygium sp.* (Myrtaceae), *Endiandra sp.* (Lauraceae), *Calamus australis* (Arecaceae), *Acmena sp.* (Myrtaceae), and *Myristica insipida* (Myristicaceae) (Hopkins and Graham, 1987; Graham and Hopkins, 1990).

## 2.2. SPATIAL AND TEMPORAL VARIATION IN SOIL SEED BANK DENSITY AND SPECIES COMPOSITION

Seed density varies greatly within the tropical soil seed bank. Variations in density can be observed between regions and ecosystem types. Seed density was also influenced by the ecology of the system, including plant functional traits. In most of the studies seed density decreases with depth. Sandrine *et al.*,(2006) and Abdella *et al.*, (2007) found that higher seed density in the 0 to 5 cm depth profile is attributable to organic matter accumulation on the soil surface of the sites. When the environmental condition are favorable and replacement is necessary, success of a seed bank depends on the seed density ready to germinate (Carvalho and Favoretto, 1995). Study conducted by Yuan *et al.*, (2012) in Qinghai-Tibetan Plateau found out that seed density increased with decreasing levels of degradation while it increased with age after restoration.

Tropical Rainforests in comparison have generally lower densities (Martins and Engel, 2007; Dainou *et al.*, 2011). Plant functional traits can influence seed density. Putwain and Gillham (1990) emphasized that a high percentage (about 96%) of seed banks due to high litter accumulation could be attributed to seasonality because at the time of sampling, the forest floor was observed to have a lot of seedlings which might have germinated from within the 0 to 5 cm depth. Increased soil depths may impair seed germination by altering moisture, air, light and temperature, hence making seeds to remain in a state of dormancy for long (Thomas, 2000; Gutterman *et al.*, 2007). In addition, Abdella *et al.*, (2007) demonstrated that average depth of seeds in the soil indicated their distribution and longevity in the soil.

The distribution of seeds in various soil depths is also attributable to several biotic factors such as the activity of ants, mole rats and other soil micro-fauna (Forget *et al.*, 1998).

Soil seed banks in tropical humid forests are found to be highly heterogeneous (Garwood, 1989; Uhl *et al.*, 1981). Some factors which results in high spatial heterogeneity of soil seed banks are the seed dispersal patterns of the different species, edaphic factors and fire and seed predation. Such constrains affect seed germination while the time of disturbance relative to flowering may limit the number of seeds and species that invade a site (Epp, 1987).

## 2.3 THE RELATIONSHIP BETWEEN SOIL SEED BANK AND SEED CHARACTERS

Thompson *et al.* (1993) suggested that soil seed bank formation is related to small seeds, because small seeds can easily enter into deep soil. A database comprised of 18 plant traits and seed bank formation or persistence data, indicated that only life history and seed size were closely related to seed bank formation, and dormancy was not essential for the formation and persistence of a seed bank. The diversity of seed size could enhance opportunities for seedling establishment in the heterogeneous environment allowing plants to respond to different sand burial depths, enhance their ability to adapt to the changing environment, and increase survival (Zhu *et al.*, 2005)

Based on relationship between seed size and soil seed bank, Yu *et al.* (2009) distinguished four patterns. First, seed weight and shape can predict persistence since small and compact seeds tend to be persistent in soil. Second, seed weight is related to persistence in soil, but seed shape is not. Third, there is apparently no relationship at all between seed weight, shape and persistence. Fourth, large seeds tend to form persistent soil seed banks, but seed shape is irrelevant.

Ma *et al.* (2010) found that seed from persistent seed bank tend to have smaller seeds than species with transient seeds. Many forest species produce small quantities of short-lived seed. As such, the conditions in typical forest environments select for traits associated with high rates of seedling establishment at the expense of dispersal in space and time (Leishman and Westoby, 1994; Warr *et al.*, 1993; Thompson *et al.*, 1997; Hermy *et al.*, 1999; Bossuyt and Hermy, 2001; Bossuyt and Honnay, 2008). This pattern is consistent with reports of low species similarity between the seed bank and extant vegetation of forested systems (Hopfensperger, 2007).

## 2.4 THE RELATIONSHIP BETWEEN SOIL SEED BANK AND GEOGRAPHIC FACTOR

Seed bank density and species richness vary along temporal and spatial gradients. Study conducted by Thompson, (1978) showed that the seed bank density decreases with altitude. Moreover, Ortega and Levassor (1997) suggested that densities of buried seeds decrease with altitude increasing because of the harsh environment at higher elevations which reduce seed production and encourage reliance on vegetative reproduction.

Alternatively, Funes *et al.* (2003) showed that seed bank richness and density increase with altitude increase as a result of two processes: the relatively warm conditions at the lower altitudinal levels may enhance the activity of seed predators, while the cold climate at the high elevations may favor the formation of persistent seed bank. Species richness of standing vegetation differed significantly with elevation.

Zahran and Willis (1992) analyzed the relationship between the slope angle and the density of buried seeds, and slope angle was found to be the most important controlling factor for the density of buried seeds, in upper basins with many steep slopes, the loss of seeds by rolling off and draining off played greater role in forming the soil seed bank than seed inputs, slope angle having the negative effects on the seeds accumulation.

If the restoration area is close to natural communities, the native species component of the seed bank density increases. Analyzing metapopulation dynamics from patch level incidence of Florida scrub plants, Quintana Ascencio and Menges (1996) suggested that the lowest richness and diversity values were found on the flat isolated area, and the greatest values were found in slope area that was in contact with the natural community, hence isolation decreases the probability of colonization.

## 2.5 SOIL SEED BANK STUDIES IN TROPICAL RAINFORESTS

Soil seed banks play an essential role in regeneration of tropical rain forests, temperate and boreal forests, although the role of these in tropical dry deciduous forests have not been fully understood (Perera, 2005).

Tropical soil seed bank studies found that pioneer species including herbs and grasses dominated the soil seed bank of primary and secondary rainforests (Guevara and Gomez-Pompa, 1972; Cheke *et al.*, 1979; Hall and Swaine, 1980; Hopkins and Graham, 1987; Graham and Hopkins, 1990; Quintana Ascencio *et al.*, 1996; Tucker and Murphy, 1997). In addition, Dupuy and Chazdon (1998) found that herbs, shrubs, and vines represented more than 75% of species in the soil seed bank in the rainforests of Costa Rica. In a review of temperate and tropical soil seed bank literature and sampling techniques, Warr *et al.* (1993) explained that woody plants dominated the soil seed bank of tropical soil seed banks. Other tropical soil seed bank studies observed that herbs and grasses dominated the soil seed bank (Uhl and Clark, 1983; Young *et al.,* 1981; Chandrashekara and Ramakrishnan, 1993; Tucker and Murphy, 1997).

Soil seed bank composition of recently rehabilitated and heavily disturbed sites were composed predominately of exotic herbaceous species, which may be a reflection of the species present on the site prior to rehabilitation (Hall and Swaine, 1980; Holthuijzen and Boerboom, 1982; Hopkins and Graham, 1987; Enright, 1985; Epp 1987).

Tropical rain forests contain large number of pioneer seed species (Whitmore, 1983). In contrast, the density of seeds in tropical dry forests is found to be low. Lieberman (1979) found a maximum of 160 seeds $m^{-2}$ in a dry forest in Ghana while Hall and Swaine (1980) observed 100 - 700 seeds $m^{-2}$ in a dry forest in the same country. In a tropical semi deciduous forest at Sigiriya Sanctuary, Sri Lanka, observed soil seed density of $166 \pm 127$ seeds $m^{-2}$ (Perera, 2005).

## 2.6. ROLE OF SEED BANK IN VEGETATION DYNAMICS

Seed bank is part of the flora of a system. Primary role of the seed bank is to ensure the continuation of species after disturbance or natural mortality that has killed the extant vegetation (Simpson *et al.*, 1989). However, population maintenance and a reserve of genetic diversity are also functions of the seed bank. The role of the seed bank in vegetation dynamics varies from system to system.

In a relatively stable undisturbed ecosystems, natural selection favour accumulation of transient seeds. Species from systems where disturbances are common generally form persistent seed banks. However if the disturbance is predictable species with transient seed banks may dominate (Thompson and Grime, 1979; Thompson *et al.*, 1993; Thompson *et al.*, 1997; Leck and Brock, 2000).

Species with seeds that lose viability after being desiccated are generally from wet areas such as rain forest or permanent wetlands or are viviparous. (Farnsworth, 2000). Recovery after disturbance may be dependent on dispersal into the disturbed area for transient seed banks. In contrast, species that have long-lived seeds or persistent seed banks do not need to rely on dispersal into the disturbed area.

The dynamics of a seed bank involves a series of events of seeds from the bank, in relation to time (Simpson *et al.*, 1989). The input is determined by the seed "rain". This way of dispersion includes passive forms, mechanical ejection of seeds, fire, wind, water and animals. The result from physiological answer of plants to environmental factors that induces the germination, seed burial or re-dispersion of the seeds, and predation of the seeds

## 2.8 SOIL SEED BANK AND REGENERATION FOLLOWING DISTURBANCE

Soil seed banks play a major role in natural regeneration after disturbances such as fire, logging and overgrazing in humid environments and determining the composition and density of seed banks is considered as an essential step in artificial restoration of degraded vegetation (Van der Valk and Pedersen, 1989). Cost-effective forest regeneration, especially natural regeneration, is one of the keystone in sustainable forestry (Jonasova *et al.*, 2006; Leinonen *et al.*, 2008).

At high levels of disturbance, seed rain account for rainforest regeneration more than soil seed bank (Cheke *et al.*, 1979; Uhl and Clark, 1983; Putz and Appanah, 1987; Garwood, 1989; Hopkins *et al.*, 1990; Chandrashekara and Ramakrishnan, 1993). In contrary Putz and Appanah (1987) found that more seeds germinated from the seed bank than seed rain following a disturbance in a tropical rainforest in Malaysia.

Campos and de Souza (2003) found that seed rain played a larger role in rainforest regeneration than the soil seed bank. In addition, Benitez-Malvido *et al.* (2001) noted that the seed rain contributed more late successional species than the seed bank in primary rainforests and pastures, and the seed bank contributed more early successional species than the seed rain in secondary rain forests.

Tropical soil seed bank studies illustrated that larger canopy gaps may be more important in initiating recruitment from the soil seed bank than smaller canopy gaps because larger canopy gaps allow more sunlight and subsequent heat to the soil surface, both of which act as triggers for germination in soil-stored seeds (Garwood, 1989; Hopkins *et al.*, 1990).

Studies, in addition to those on canopy gaps, have emphasized the importance the soil seed bank may play on regeneration following disturbances. Young *et al.*, (1987) studied tropical rainforests over a variety of successional stages in Costa Rica. They discovered that within one year following a disturbance, the soil seed bank decreased dramatically due to seed germination, indicating the importance of the seed bank for vegetation response to disturbance. The soil seed bank began to accumulate in the following years to reach a peak at four to seven years, when it slowly declined and reached a density of its pre-disturbed state. To support further, two studies in India and Puerto Rico reported that soil seed banks in recent disturbances appeared to be lower in seed abundance and species richness than sites that had not been recently disturbed, which suggests increased recruitment is occurring from the soil seed bank following disturbances (Chandrashekara and Ramakrishnan, 1993; Cubina and Aide, 2001).

The seed longevity in the soil varies among species, characteristics of the seeds, burial depth, and climatic conditions (Carmona, 1992). Limited seasonal variation in rain forest soil seed banks has been recognized (Enright and Cameron 1988; Guevara and Gomez-Pompa, 1972). In contrast Chandrashekara and Ramakrishnan (1993) showed that the density of germinable seeds in a humid forest seed bank of Western Ghats of Kerala, India, fluctuates considerably with time of the year, and the seed density was high during the monsoon season. Density of seed banks decline with increasing depth of the soil (Pickett and McDonnell, 1989; Saulei and Swaine, 1988). Buried seed banks regarded as persistent appear to be an important source of plant colonists in some secondary successions in the tropics (Kellman, 1970; Symington, 1933).

The dormancy represents a main mechanism of species preservation in the seed bank, distributing the germination through the year. It can guarantee the species survival in the form of seeds, under adverse conditions, even when the population of plants is completely eliminated (Carmona, 1992).

Bernhardt and Ulbel, (2000) reported that the degraded natural forest sites are mostly invaded by non-tree plants such as ferns, vines, grasses and shrub at the expense of tree species, which may take decades to recruit. They further found that herbaceous species have better chances of recovery than tree species from the soil seed banks in the event of disturbance. Abdella *et al.* (2007), found that seed bank density and dominance by weeds increases with continuous farming. Perera (2005) studied potential role of the soil seed banks in forest regeneration and succession following a large-scale disturbance along a chronosequence of forest age. Soil seed banks of young successional forests were dominated by agricultural weeds, and their seeds were mainly dispersed by wind. Therefore, such seed banks do not often contribute to the forest regeneration. After about 20 years, the diversity of the soil seed bank increased and the seed banks contained some forest tree and shrub seeds. Since the microclimate of such forests are more favorable for seed germination and seedling establishment, seeds which reach these forests might germinate and establish well, contributing to successful forest regeneration and succession. Seed bank of mature forests contain less number of seeds but are also dominated with grass and agricultural weed species. After a large-scale disturbance these seed banks cannot support the natural regeneration of tropical semi-deciduous forests.

## 2.9 SIMILARITY BETWEEN SOIL SEED BANK FLORA AND ABOVEGROUND VEGETATION

Researchers have examined the relationship between seed banks and standing vegetation to study the effects of restoration and reforestation, the effects of disturbances, succession, invasive species, and management techniques (Hopfensperger, 2007). The primary variable measured when studying seed bank vegetation relationships is floristic similarity. Sorensen's index of similarity (Sorensen, 1948) was used widely to calculate the floristic similarity between seed bank and standing vegetation. Persistent seeds of several common pioneer, edge, and alien species require light for germination and when the seeds persist through time, they fail to germinate in the later successional stages of forests due to decreased light intensity and the thick litter layer (Devlaeminck *et al.*, 2005). Understanding the similarity of species composition between a seed bank and standing vegetation and whether trends exist over various spatial and temporal scales can provide insight into whether the seed bank is driving vegetation composition, or the vegetation is driving seed bank composition (Leck and Simpson, 1987, Henderson, 1988).

Mechanisms responsible for low similarity in forest ecosystems included large seed size and seed predation of late succession species (Decocq, 2004). Gashaw, (2002) found many woody seeds attached to the pods remaining in the litter layer in an Ethiopian forest, which not only makes the seeds vulnerable to predation, but also keeps them from contributing to the seed bank. Furthermore, some have claimed that late succession forest species have larger seeds that are targeted for predation by small mammals on the forest floor (Argaw *et al.*, 1999; Yorks *et al.*, 2000). Exceptions to the rule of forests having low similarity were found. For example, forest above and belowground communities had higher similarity in stable systems where the vegetation drove the seed bank composition (Johnson, 1975).

Several studies conducted throughout in tropics revealed that soil seed bank is not a representative of standing vegetation, even though invasive species had a surprisingly little impact on the soil seed bank . Native annual species present in high abundance across all treatments, represents 68% of the soil seed bank composition. Native perennials are an important group and are the focus of restoration efforts. Without these species, restoration is unlikely to be successful; however this group only represented a fraction of the composition (17%).

Thomas (2000) and, Valbuena and Trabaud (1995), found little similarity between soil seed bank species and above ground vegetation. However, there are exceptions as found mainly in annual dominated communities that often contain early succession species, but do not represent late or dominant succession species (Robert *et al.*, 2000). This difference may be due to seed dispersal mechanisms, seed burial and predation or even decomposition.

Ma *et al.*, (2010) examined the role of the soil seed bank along a grazing disturbance gradient and its relationship with the vegetation of alpine meadows on the Tibet plateau and suggested that among 62 species identified in the vegetation and 87 in the seed bank, 39 species were common to both. Significant differences of species composition between seed bank and vegetation was found except for the seriously disturbed sites.

Elizabeth's (2006) study indicated that cover and diversity of standing vegetation changed as tree cover increased. However, the soil seed bank did not differ in overall seed density or species diversity because the 13 species that comprised 86% of the seed bank occurred in similar density across the tree cover groups. Interestingly, 63% of the species that were in the seed bank were absent from the vegetation, and these species were mostly annual herbs. In addition 49% of the species that occurred in the standing vegetation were not found in the seed bank, and these species were perennial forbs and subshrub/shrubs.

A research of the relationship between soil seed bank and above ground vegetation of eight species at four different sites, showed that there were no species overlaps between soil seed bank and established vegetation at two sites. Six species from extant vegetation were absent from the seed bank at one site. They concluded that both seedling density and species richness of the soil seed bank among the four sites were significantly different (Wódkiewicz and Kwiatkowska, 2010). The study of characteristics and dynamics of the soil seed bank at the north edge of Taklimakan Desert reported that there were seven plant species in the above ground community and nine plant species in soil seed bank, out of this two species were found in soil seed bank but did not exist in the aboveground vegetation community (Wellstein *et al.*, 2007). In addition, the similarity between the aboveground vegetation and the soil seed bank in a Mediterranean coastal sand dune were found to be seasonally dynamic with highest similarity value occurring during May to September and the lowest value at about the end of April when no new seedlings were emerging (Yu *et al.*, 2008).

Rico-Gray and Garcia-Franco (1992) studied similarity between the seed bank and standing vegetation composition along a successional gradient in a tropical deciduous forest. They found slash and burn disturbances to be driving community composition with higher similarity between seed bank and vegetation shortly after the disturbance and similarity decreasing with succession after the disturbance. Increased light from the openings created from slash and burn practices became the main mechanism controlling the similarity between the seed bank and vegetation.

The soil seed bank was sampled in forest, recent gaps and arable land at a site within the dry Afro-montane forest belt in eastern Ethiopia. The regeneration in the gaps was also followed for three years. At least 32 species of flowering plants were identified in the 0-3 cm soil layer with total densities ranging between 9400 and 20740 seeds/m $^{2.}$ The highest number of species was recorded from the forest while the highest seed density was found in the arable land. Contribution of woody species to the soil seed bank was 15% in the forest while it was less than 1% in gaps and arable land (Teketay, 1996).

Study conducted by Perera (2005) in tropical semi deciduous forest of Srilanka showed that soil seed banks are highly heterogeneous and heterogeneity is greatly affected by composition of the local vegetation, fruiting season and the seed dispersal patterns. They added that invasion of forest into grasslands would not occur spontaneously, while disturbance in forest or forest edge promote herbaceous seed thus reduction in forest cover and expansion of grassland.

Pratima and Kharae (2012) examined the soil seed bank of dry deciduous forest in central India, and found that upper layer of soil act as a good seed depository as seeds of 34 species in which 17 species belonging to tree species were recovered. Highest density of seeds were recorded in case of *Anogeissus pendula* 800 $m^{-2.}$

Senbeta and Teketay (2002) investigated soil seed banks in plantation and adjacent natural stand in Ethiopia and found that seed density range from 27,200-82,600 in natural stand and 4500-36,900 seeds per sq. m. in plantations. Herbs dominated both in the number of species and densities of seeds while the contribution of woody species was generally low. Vertical distribution of seeds in the soil was similar in all stands with the highest densities occurring in the upper three centimeters of soil with gradually decreasing densities with increasing depth. Woody plants representation in soil seed bank were very few which suggest that most woody plants rather use the seed rain, seedling banks or coppicing from stumps as alternative regeneration routes than seed bank. Similarity in species composition of soil seed bank was done using Jaccards coefficient of similarity index. The plantation had lowest value 0.17 and natural forest had a value of 0.69.

The low species richness of the soil seed banks relative to high species richness of the aboveground vegetation in the mixed-native plantation could be due to humid and wet conditions, which increases mortality of seeds on the soil surface (Sester *et al.*, 2006).

Mukhongo *et al.*, (2011) assessed soil seed bank from different vegetation types including forest, plantation and grasslands in Kakamega forest, Western Kenya. Seed viability tests revealed low seed viability for the seeds from all the sites. It was concluded that natural regeneration is slowed by low woody species which ranged from 5.7 for natural glade to 48.4% for natural forest soil seed bank, and a low seed viability that ranged between 1.3 for plantation to 33.8% for grassland. It was therefore suggested to consider other ways of forest restoration other than the soil seed bank.

Soil seed banks between a secondary natural forest and an adjacent big leaf mahogany plantation in Philippines were examined by Han *et al.* (2012) to understand seed bank dynamics, the relationship between soil seed bank and aboveground vegetation and effects of canopy gaps on soil seed banks in a tropical rain forest. They reported only three species in the secondary natural forest and six species in the big leaf mahogany plantation were commonly found in both soil seed banks and aboveground vegetation. Most of the species in soil seed banks were pioneer or mid seral species which came from the outside of the stands.

## 2.10 SOIL SEED BANK CONTRIBUTION TO ECORESTORATION

Soil seed bank plays an important part in the vegetation restoration process, and it seems to be essential that management plans take in consideration the differences in seed bank development of each site. The process of ecological restoration consists of directing an ecosystem development towards a target ecosystem, often by accelerating succession or skipping successional stages. Generally, restoration seeks to plant a group of species that possess different dispersal mechanisms in order to increase natural levels of seed dispersal, and to encourage continued recruitment of new cohorts of native species (Tucker and Murphy, 1997; Tucker, 2001; White *et al.*, 2004). Exotic species are considered as a threat to restored sites because they have the potential to retard native species recruitment (Holzner, 1978; Ashton *et al.*, 1997; Groves and Willis, 1999). If exotic species germinate, fruit, and dominate rehabilitated sites, then rehabilitation practices have not fulfilled their aim because the sites are not catalyzing natural successional processes and the vegetation will not progress toward community composition similar to remnant rainforest.

Soil seed banks can be a source of colonizing species that can restore degraded ecosystems or accelerate forest succession (Augusto *et al.*, 2001; Luzuriaga *et al.*, 2005). The composition of the seed banks mainly depends on seed production and composition of the seed sources, which consist of current and previous vegetation. In managed forests, the quantitative and qualitative characteristics of the seed banks are often affected by the silvicultural system management (Augusto *et al.*, 2001; Godefroid *et al.*, 2006). Knowledge of the composition of the soil seed bank is essential to determine whether the restored sites are catalyzing natural successional processes. It can also be used to predict vegetation dynamics and community-level changes in species composition and relative abundances (Campos and de Souza, 2003).

The study of soil seed bank along a degradation gradient in arid rangelands of the Somali region, showed that soil seed banks did not improve the condition of it through restoration (Kassahun, 2009). Ma *et al.* (2010) have suggested that the establishment of new species in severely disturbed areas is more dependent on the seed bank. The restoration in less disturbed and mature meadows did not rely on seed banks, and the establishment of the vegetation in these communities is more likely to rely on seed dispersal from the standing vegetation and on species with vegetative reproduction.

One principle factor limiting the efficacy of rehabilitation plantings is the location in which rehabilitation work is conducted. Isolated rehabilitated sites are more susceptible to wind disturbance, microclimate change, and weed invasion (Laurance, 1997). Therefore, recruitment to isolated rehabilitated sites may differ significantly from rehabilitated sites adjacent to remnant rainforest. One of the principal mechanisms limiting species recruitment to isolated rehabilitated sites is seed dispersal. Many seeds are not developed for dispersal over long distances (Takahashi and Kamitani, 2004) and rely on local dispersal.

Some birds require large continuous rainforest for survival and are unlikely to travel to small isolated rehabilitated sites. Therefore, seeds of some plant species may never disperse to rehabilitation sites isolated from remnant rainforest. Conversely, many isolated rehabilitated sites are surrounded by pastures, with abundant exotic species that produce many small highly-mobile wind-dispersed seeds. Therefore, isolated rehabilitated sites may have a higher concentration of exotics than remnant rainforest sites or adjacent rehabilitated sites (White *et al.*, 2004).

Trevor *et al.* (2012) examined the potential role of the soil seed bank in restoration of an open eucalypt forest community. They used plant functional traits responsive to disturbance and other traits associated with the capacity to recolonize and form persistent seed banks as a means of assessing the effects of land-use change on soil seed banks. Based on functional traits seed banks were dominated by traits associated with the rapid acquisition of resources or the ability to respond rapidly to disturbance that provided for large and persistent stores of introduced ruderal species. In contrast, species excluded from the seed bank shared traits associated with the conservation of resources or ability to withstand environmental stress and were typical of native phanerophytes. The authors conclude that these generalisable patterns in plant traits make it unlikely that eucalypt communities can be restored from the native soil seed bank alone.

In an experiment conducted by Miranda *et al.* (2007) showed that transposition of soil seed bank is a viable technique adopted to restore forest restoration. Fowler (2012) conduct an experiment to make comparisons between the soil seed bank pre and post-transfer, an aspect of topsoil transfer that has not been looked at previously. Seventy-three per cent of germinants were found in the top 5 cm of natural (pre-transfer), soil transfer leading to mixing (no depth effect) and a reduction in germinant densities (2472.00 germinants $m^{-2}$). Treatment with germination cues increased germinant densities by 1537.80 germinants $m^{-2}$, however no increase in transferred soils was observed. Native annuals dominated species composition of transferred soils, contributing 68% of observed richness, with woody species only accounting for 9% overall. The similarity of the soil seed bank to the standing vegetation ranged from 15% to 19%, the higher similarity found when treatment was used. Overall topsoil transfer is a useful tool for restoration; however it must be used in conjunction with other methods, such as planting and direct seeding, to return a representative set of species to a site.

Ren *et al.* (2002) observed that ecorestoration with pioneer species show fast recovery of degraded lands and sometimes support native understory species, but they do not lead to natural forests. Also succession does not result in forests that resemble the native forests in the area. Instead, succession in artificial forests of Pinus, Eucalyptus, and Acacia is arrested at the pioneer stage, which is characterized by simple structure, reduced biodiversity, and ineffective ecosystem functioning and services. Ren *et al.* (2011) added that silvicultural management encourages acceleration of plantation succession to more natural stages.

A study was conducted to evaluate the soil seed bank diversity across a range of ages of *Eucalyptus grandis* plantations afforested on arable lands (Zheng *et al.*, 2004). Initial year of plantation establishment was associated with lower plant and soil seed bank diversity, meriting a greater focus on biodiversity stabilization and possibly longer rotation periods. *Eucalyptus grandis* likely produces a changing microclimate during plantation development, which in turn drives composition and diversity dynamics in understory vegetation and soil seed banks after the afforestation of agricultural land.

Soil seed banks offer the potential to assist restoration efforts depends other factors, like the richness and density of native species represented across successional groups and of non-target or invasive species (Lang and Halpern, 2007). Calegiri *et al.* (2013) evaluated the potential of soil seed bank to forest restoration and found out that the large number of regenerating herbaceous plants reduce the forest restoration. The success of restoration is directly linked to the activities of competitive species. In a study the result showed that irrespective of vegetation type soil seed banks of target species is very sparse also they do not guarantee the regeneration of species-rich vegetation (Valko *et al.*, 2010).

Lack of seeds of desirable species in the seed banks and unfavorable environmental conditions for seed germination and seedling establishment (Shono *et al.*, 2006) can substantially limit colonization by indigenous tree species and thus hamper succession. Therefore, to better understand regeneration in artificial forests, we need to analyze the size and species composition of soil seed banks in plantations and to identify factors contributing to succession.

Zheng *et al.* (2004) observed that seed banks of plantations established on degraded hilly land in South China was dominated with herbaceous species. Nearly 78% of seeds in the soil seed banks were herbaceous. Moreover, there were more herbaceous seeds in the 5-10 cm soil layer than in the 0-5 cm soil layer. The high density of herbaceous seeds in the seed bank may be related to species traits. An earlier study observed that herbaceous seeds in the soil remain viable for longer than other seed types (Ghersa and Martinez- Ghersa, 2000). Seed persistence in soil is also related to microsite conditions that partially regulate seed germination or dormancy (Reuss *et al.*, 2001). As plantations mature, the increasingly shaded conditions of the understory would inhibit germination of light requiring herbs.

Wang *et al.* (2009) compared soil seed banks of plantation in South China to better understand the potentials of the soil seed banks in facilitating succession towards a more natural forest of native tree species. A total of 1211 seedlings belonging to eight species emerged in a seedling germination assay, among which *Cyrtococcum patens* was most abundant. All species detected were shrubs and herbs, and no viable indigenous tree seeds were found in soil samples. Size and species composition of the seed banks might be related to the over story species compositions of the established plantations. The seed bank density in soils was highest in the mixed-conifer plantation followed by Eucalyptus, mixed-native, and legume plantations. The results indicated that the soil seed banks of the current plantations are ineffective in regenerating the former communities after human disturbances. Particularly, the absence of indigenous tree species seeds in the seed banks would limit regeneration and probably contribute to arrested succession at the pioneer community stage. It would appear from these data that the soil seed banks under the current plantations should not be considered as a useful tool leading the succession to more natural stages. Introduction of target indigenous species by artificial seeding or seedling planting should be considered to accelerate forest regeneration.

Reviewing the literature, it was noted that studies regarding the soil seed bank in ecorestored area was scanty. The literature cites only few works with respect to tropical soil seed bank studies. Hence the present study is oriented to explore on the above mentioned topics and thus would be useful in seed bank and ecological studies.

# MATERIALS AND METHODS

# 3. MATERIALS AND METHODS

## 3.1. STUDY AREA

### 3.1.1 Name, Location and Extent

Attappady is located in the North eastern part of Palakkad district, in the Western Ghats region of Kerala, India. It lies between $10^0$ 55'and $11^0$ 15'N latitude and $76^0$ 22' and $76^0$ 46'E longitudes; spread over three panchayats of Agali, Pudur and Sholayur. This area is part of the Nilgiri Biosphere Reserve.

It is bounded in the North by Nilgiri District (Tamil Nadu), in the West by Malappuram District (Kerala), in the South by Palghat Taluk (Kerala) and in the East by Coimbatore District (Tamil Nadu).

Out of the total area, Forest land constitutes 444.07 $km^2$, Agricultural land comprises 130.03 $km^2$. The area under wasteland is about 157.31 $km^2$, rivers and roads constitute 14.49 $km^2$. The total land area thus comprises 745.9 $km^2$ (India census, 2001).

### 3.1.2 Geology, rock and soil

Mani and Lahiri have studied the geology, lithology and mineralogy of the area and according to them, the major geological formations are peninsular gneisses, Quartz-Biotite schist and Magnetite-Quartzite. Peninsular gneisses occupy the southern part of the valley (Vidyasagaran and Anilkumar, 2009).

The soil is originated from weathering of parent material, Archean crystalline

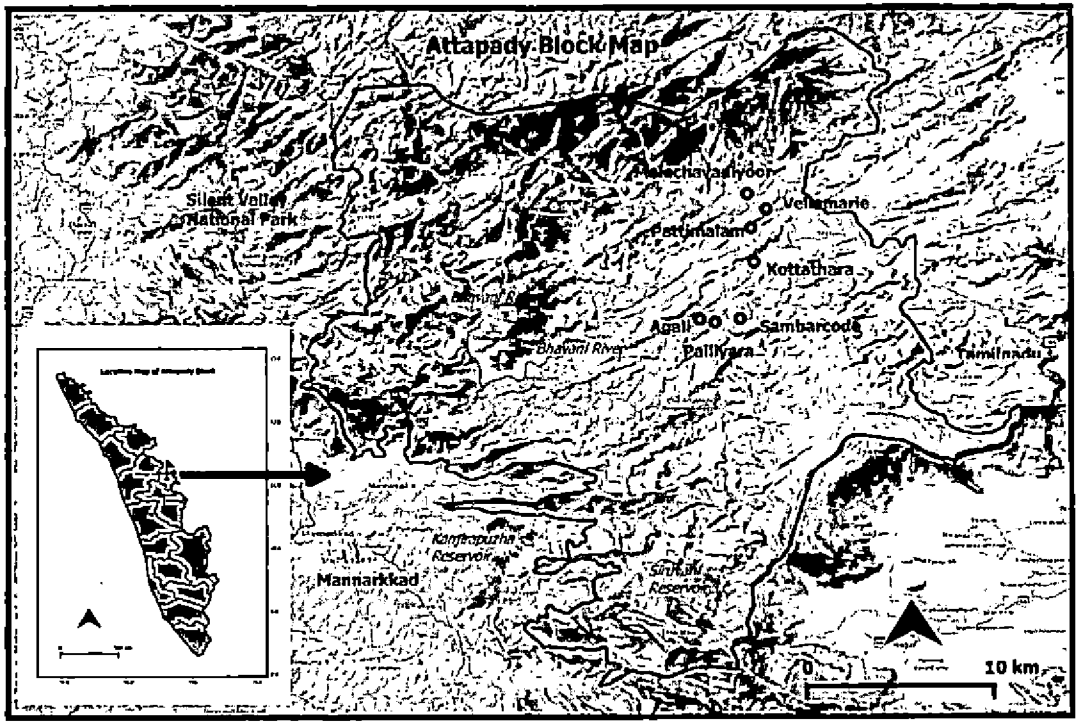



Fig. 1. Location map of study area in Attappady

and metamorphic rocks such as garnetiferous gneiss, biotite gneiss amphibolite, crystalline lime stones and granites under sub humid to semi-arid climate and under evergreen, semi- evergreen, moist deciduous and dry deciduous types of vegetation. Soils under evergreen and semi-evergreen forest are brown to dark yellowish brown, where those under moist and dry deciduous forests are dark brown to dark greyish brown in colour. The surface horizons of these soils have the following general features: loam to sandy loam texture, slightly acid to neutral reaction, fairly high content of organic carbon except in dry deciduous forest area and fairly high cation exchange capacity values.

### 3.1.3 Terrain

Physiographically, the area is divisible into three regions.

- The valley proper
- Nilgiri range along the northern side
- Vellingiri range on the southern side

The valley region is rugged, the elevation ranging from about 250 m to about 1700 m, particularly in the western portion. Towards East, it is less undulating and gently sloping, merging with the plains of Coimbatore District of Tamil Nadu. The highest peak is Malleswaramalai (1664 m) and other important peaks are Taikarai (1554 m), Tokkuppannamaliai (1605 m) and Taimbhagavathimalai (1014 m). Nilgiri range is characterized by steep slopes, cliffs and rocky outcrops, elevation ranging from 1600 m to about 2300 m. Vellingiri range is also broken but less unevenly and the gamut is from about 750 m to 2100 m (Fig. 1).

### 3.1.4 Climate

#### 3.1.4.1 Rainfall pattern and distribution

The area receives rainfall both from South West and the North East monsoons during June-August and October-December respectively. While the western hilly areas receive the bulk of precipitation during the South West monsoon, the main quantum of precipitation in the eastern plains is by the North East monsoon. Average rainfall in the Western region is 2500 mm/year whereas the Eastern region gets less than 600 mm/year.

The rainfall pattern in the eastern part exhibit a tropical dissymmetric regime where the peak of the rainy season is shifted towards the end of the year and not centered as in rest of Kerala. They receive scanty rainfall during October to November and inter-yearly variability of rainfall is very much conspicuous (Basha, 1987).

Thus, based on the distributional pattern of rainfall at least two main regimes can be recognized with a transitory stage. The western portion is wet, warm and humid for nearly nine months in a year. The eastern portion is dry and warm almost throughout the year. The influence of these two distinct regimes is reflected in the vegetation distribution.

Table 1. Average rainfall in mm (Vidyasagaran and Anilkumar, 2009)

| Month | Karuvara | Choottara | Mully | Agali | Sholayur | Kottathara | Kallamala | Vattulacky |
|---|---|---|---|---|---|---|---|---|
| January | 4.18 | 5.13 | 9.16 | 14.47 | 6.36 | 7.97 | 0.00 | 7.17 |
| February | 12.50 | 7.00 | 6.69 | 38.92 | 30.73 | 47.92 | 21.8 | 6.71 |
| March | 43.44 | 66.08 | 37.76 | 69.8 | 67.36 | 38.43 | 10.33 | 33.78 |
| April | 31.20 | 127 | 112.86 | 92.58 | 156.07 | 93.94 | 102.63 | 47.71 |
| May | 78.00 | 87.48 | 55.81 | 111.18 | 130.07 | 60.51 | 223.63 | 35.34 |
| June | 318.90 | 61.58 | 49.94 | 131.5 | 264.36 | 74.89 | 427.1 | 26.56 |
| July | 302.40 | 69.90 | 50.24 | 88.92 | 256.65 | 86.66 | 530.24 | 25.74 |
| August | 243.25 | 30.73 | 64.14 | 64.46 | 160.9 | 48.21 | 315.64 | 34.96 |
| September | 156.89 | 63.80 | 71.22 | 74.84 | 128.07 | 101.33 | 175.11 | 69.02 |
| October | 277.30 | 259.36 | 302.76 | 260.82 | 291.7 | 320.53 | 362.6 | 162.32 |
| November | 102.9 | 160.07 | 247.77 | 120.57 | 291.86 | 205.16 | 137.52 | 146.97 |
| December | 11.7 | 6.25 | 98.09 | 22.33 | 69.37 | 62.13 | 63.04 | 35.29 |

3.1.4.2 Temperature

It is seen that March, April and May are the hottest months of the year and there is a wide range of variation between the plains and the hills. December, January and February are the coldest months of the year. The mean annual temperature in the plains varies from 21 to 40° C and in the hills from 10 to 32° C (KFRI, 1991). The occasional thunderstorms during May considerably reduce the temperature in the western portion (Table 2).

Table. 2. Maximum and minimum temperature (Vidyasagaran and Anilkumar, 2009)

| Month | Maximum Temperature | Minimum Temperature |
|---|---|---|
| January | 26.03 | 15.39 |
| February | 27.21 | 15.97 |
| March | 29.38 | 18.66 |
| April | 29.14 | 20.83 |
| May | 27.95 | 22.04 |
| June | 24.30 | 19.79 |
| July | 24.83 | 21.08 |
| August | 23.46 | 20.15 |
| September | 22.30 | 18.34 |
| October | 25.11 | 19.44 |
| November | 25.34 | 18.06 |
| December | 23.62 | 15.58 |

### 3.1.5 Water Source

The major rivers of Attappady hill are Bhavani and Siruvani. River Bhavani originates from Nilgiris flows to south up to Mukkali and takes a turn to east. Further, it flows in the north- east direction draining to Tamil Nadu. The tributaries of Bhavani, East and West Varahapallam join Bhavani at Ranganathapuram. River Siruvani which originates in the Vellingiri range flows through Muthikkulam (Where it is impounded by Siruvani dam) and joins river Bhavani at Koodapatty, the Kerala - Tamil Nadu border.

### 3.1.6 Habitat and Vegetation

The forests of Attappady, even within the limited geographical area, exhibit considerable variation in floristic composition, structure and physiognomy due to climatic, physiographic and edaphic influences. Its present status is further determined by biotic, particularly anthropogenic influences. The forests thus offer considerable scope for an intensive study of the influences of natural as well as introduced factors.

The forest can be classified into different forest types based on the classification of Champion and Seth (1968).

- West coast tropical evergreen forest
- West coast semi-evergreen forest
- South Indian moist deciduous forest
- Southern moist mixed deciduous forest
- Southern tropical dry deciduous forest
- Southern tropical dry deciduous scrub
- Southern subtropical broadleaved hill forest
- Southern montane wet temperate forest (Sholas)
- Southern montane wet grassland

## 3.2 METHODS

### 3.2.1 Site selection

Of the total forest area of 444 $km^2$ in Attappady, a major part ie. 210 $km^2$ was degraded and was facing severe desertification threat (KFRI, 1991). The major focus of Attapady Wasteland Comprehensive Environmental Conservation Project (AWCEP) undertaken by AHADS is the improvement and conservation of the areas. Firstly, they categorised the entire area in to biomass and plantation based on vegetation cover. The area which had a vegetation cover of 40 percent or more were treated as biomass. The area was then left to natural growth and regeneration and was given protection from all external influences including grazing and forest fire. The area, which were having vegetation below 40 percent, were treated as plantation by planting 10-15 different tree species, which were suitable for the area (Plate 1). The plantation was also protected from all external influences. Non ecorestored area such as revenue land and other private lands adjacent to plantation and biomass were also selected for study.

Study sites were selected by discussing with officials. Special care was taken to include all forest types in study sites. In the present study, seven plantations, three biomass area and five non ecorestored area were studied.

### 3.2.2 Sample plots

Size of quadrat was adopted from earlier study conducted in the study area (Vidyasagaran and Anilkumar, 2009). Transects were made in each site and quadrats of 20 X 20 $m^2$ size were established in a minimum distance of 200 m along the transect. All the plants in each quadrat were identified and trees equal to and above 10 cm gbh were enumerated. Information like number of species, number of individuals of each species and GBH were recorded. The numerical data obtained were analyzed to find out density, abundance, relative frequency, relative density, percentage frequency, percentage frequency, basal area and important value index using standard formula (Curtis and Mc Intosh, 1950). In addition to this, various diversity indices like Simpson's index (Simpson, 1949), Shannon-Wiener's index (Shannon, 1948) were also worked.

1. Density = No. of trees / Hectare
2. Relative Density = No. of individuals of the species x 100/ No of individuals of all species
3. Abundance = Total no. of individuals of a spp. in all quadrats / Total no. of quadrats in which the spp. occur
4. Percentage Frequency = No. of quadrats of occurence x 100 / Total no. of quadrats studied.
5. Relative Frequency = No. of occurence of a species / No. of occurence of all species.
6. Basal Area = $(GBH)^2/4\pi$
7. Relative Basal Area = Basal area for the species x 100/ Basal area of all species
8. Importance Value Index = Relative Density + Relative Frequency + Relative Basal Area

### 3.2.3 Plant Diversity Indices

Diversity indices like Simpson's index and Shannon- Weiner's function were found out using the following formulae:

1. **Simpson's index, (D)** (Simpson, 1949)

$$D = 1 - \Sigma(ni/N)2$$

This index is a measure of the dominance.

2. **Shannon-Weiner's index (H')** (Shannon, 1948)

$$(A)\ H' = 3.3219(\log N - \frac{1}{N}\Sigma\, ni \log ni)$$

$$(B)\ H_{max} = 3.3219 \log_{10} S$$

Where,

N - Total number of all individuals of all the species.

ni - No. of individuals of a species.

S - Total no. of species

### 3.2.4. Regeneration survey

Each quadrat was randomly divided into 10 sub quadrats of size 1m x 1m. All plants less than 10 cm girth were identified and information like number of individuals of each species were counted. From the data Relative density and Abundance were calculated.

### 3.2.5. Soil sampling

Soil samples were collected from experimental plot at four month interval over a period of one year. The first sampling was done in the March 2013, at the beginning of long dry period. A random location was selected along one of the axes of experimental plot. Five soil samples of 30 x 30 $cm^2$ surface areas to a depth of 5 cm were carefully removed and put in labeled polythene bags (Plate 1). The collected soil samples were taken to a shade house. This procedure was repeated on two further occasions, at the beginning of the July and at the end of October, 2013.

Plate 1. Soil seed bank sampling


Plate 2. Germination tray

### 3.2.6. Seedling emergence technique

Seedling emergence technique is used to estimate seed density and floristic composition (Roberts, 1981). At first, coarse debris were removed from the soil sample collected. Each soil sample was then spread on a layer of sand (2 cm thick) in a seed germination tray. The soil for each site was spread evenly among 5 labeled trays (Plate 2). There were a total of 75 germination trays. All germination trays were watered daily to keep the soil moist. Newly germinated seedlings that were identified at the species level were counted and then removed from the seed trays. Unidentified seedlings were transplanted into poly bags for further growth until the species could be positively identified. Five seed trays filled with sterilized sand only were used as a control for seed contamination of the sand. Each germination assay continued for up to four months (Plate 3).

### 3.2.7. Sorensen similarity index

Comparisons between the number of species in seed banks and aboveground vegetation in each quadrat was estimated. Similarities in species composition between the soil seed banks and corresponding vegetation were analyzed using Sorensen similarity index

$$SI = 2a/(b \div c)$$

Where 'a' refers to the number of species common to both the seed bank and the aboveground vegetation, and 'b' and 'c' represent total number of species detected in the seed bank and the corresponding aboveground vegetation, respectively (Cox, 1985).

Plate 3. Germination assay

### 3.2.8. Statistical Analysis

Data obtained where subjected to various multivariate analysis such as Cluster analysis and principal component analysis (PCA) using V 20. XLSTAT software.

# Results

# 4. RESULTS

The study on "Impact of ecorestoration on soil seed bank of Eastern Attappady, Kerala" was carried out during the period 2012-2014. The results obtained from this study are explained below;-

## 4.1. Vegetation studies

### 4.1.1. Species composition and vegetation structure

#### 4.1.1.1. Species composition and vegetation structure of Agali plantation

In this plantation, a total of 485 individuals of GBH> 10cm belonging to 36 different species were recorded over a 4000 $m^2$ sampling area (Table 3). Structural analysis indicated that *Leucaena leucocephala* had maximum relative density (36.91) followed by *Albizia amara* and *Santalum album* (7.84 and 7.63). Lowest values were recorded for *Stereospermum colais, Bauhinia racemosa* and *Bombax ceiba* (0.21). High abundance was recorded for *Leucaena leucocephala (22.38)* followed by *Albizia amara* (7.6) and *Santalum album* (6.17). The lowest abundance value was obtained for *Albizia procera* (0.83).

Distribution of species in the above plantation area indicated the maximum relative frequency for *Acacia ferruginea* and *Leucaena' leucocephala* (6.56). The lowest relative frequency was recorded for seven species including *Givotia moluccana* and *Murraya koenigii* (0.82). Relative basal area was worked out to be highest for *Leucaena leucocephala* (22.94) followed by *Senna siamea* (13.02) and *Albizia amara* (10.52), whereas lowest value was obtained for *Bombax ceiba* (0.04).

Important value index were studied by taking into account the values of relative density, relative frequency and relative basal area. Maximum IVI was observed for *Leucaena leucocephala* (66.41) and the lowest for *Bombax ceiba* (1.07).

Table 3. Structural analysis of vegetation in Agali Plantation at Attappady

| Sl No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia sps.* | 0.82 | 2.46 | 0.35 | 3.64 | 1.33 |
| 2 | *Acacia ferruginea* | 6.19 | 6.56 | 10.52 | 23.26 | 3.75 |
| 3 | *Albizia amara* | 7.84 | 4.10 | 6.51 | 18.45 | 7.60 |
| 4 | *Albizia lebbeck* | 1.65 | 3.28 | 3.97 | 8.90 | 2.00 |
| 5 | *Albizia odoratissima* | 0.62 | 2.46 | 1.02 | 4.10 | 1.00 |
| 6 | *Albizia procera* | 1.03 | 4.92 | 2.35 | 8.30 | 0.83 |
| 7 | *Anogeissus latifolia* | 1.65 | 3.28 | 1.37 | 6.30 | 2.00 |
| 8 | *Azadirachta indica* | 2.06 | 2.46 | 0.98 | 5.50 | 3.33 |
| 9 | *Bauhinia racemosa* | 0.21 | 0.82 | 0.19 | 1.22 | 1.00 |
| 10 | *Bombax cieba* | 0.21 | 0.82 | 0.04 | 1.07 | 1.00 |
| 11 | *Cassia fistula* | 0.62 | 1.64 | 0.84 | 3.10 | 1.50 |
| 12 | *Cassine albens* | 2.89 | 2.46 | 5.69 | 11.03 | 4.67 |
| 13 | *Dichrostachys cinerea* | 1.24 | 3.28 | 1.27 | 5.79 | 1.50 |
| 14 | *Diospyros cordifolia* | 2.47 | 2.46 | 0.78 | 5.71 | 4.00 |
| 15 | *Givotia moluccana* | 0.21 | 0.82 | 4.78 | 5.81 | 1.00 |
| 16 | *Gmelina arborea* | 1.24 | 2.46 | 0.93 | 4.63 | 2.00 |
| 17 | *Grewia tiliifolia* | 0.82 | 1.64 | 0.83 | 3.29 | 2.00 |
| 18 | *Grevillea robusta* | 0.62 | 1.64 | 0.16 | 2.42 | 1.50 |
| 19 | *Holoptelea integrifolia* | 1.44 | 4.10 | 1.08 | 6.62 | 1.40 |
| 20 | *Jacaranda mimosifolia* | 0.62 | 2.46 | 0.46 | 3.54 | 1.00 |
| 21 | *Leucaena leucocephala* | 36.91 | 6.56 | 22.94 | 66.41 | 22.38 |
| 22 | *Morinda pubescens* | 1.03 | 0.82 | 1.15 | 3.00 | 5.00 |
| 23 | *Murraya koenigii* | 0.21 | 0.82 | 0.12 | 1.15 | 1.00 |

| Sl No | --- Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 24 | *Naringi crenulata* | 2.27 | 4.10 | 2.32 | 8.69 | 2.20 |
| 25 | *Phyllanthus emblica* | 1.24 | 1.64 | 0.84 | 3.71 | 3.00 |
| 26 | *Pongamia pinnata* | 0.41 | 0.82 | 0.31 | 1.54 | 2.00 |
| 27 | *Santalum album* | 7.63 | 4.92 | 4.40 | 16.94 | 6.17 |
| 28 | *Senna siamea* | 4.74 | 4.10 | 13.02 | 21.86 | 4.60 |
| 29 | *Simarouba glauca* | 2.68 | 2.46 | 2.65 | 7.78 | 4.33 |
| 30 | *Stereospermum colais* | 0.21 | 0.82 | 0.08 | 1.10 | 1.00 |
| 31 | *Strychnos potatorum* | 0.82 | 2.46 | 0.42 | 3.70 | 1.33 |
| 32 | *Tamarindus indica* | 1.03 | 4.10 | 0.45 | 5.58 | 1.00 |
| 33 | *Tectona grandis* | 1.65 | 4.92 | . 0.86 | 7.43 | 1.33 |
| 34 | *Trewia nudiflora* | 1.24 | 2.46 | 2.14 | 5.84 | 2.00 |
| 35 | *Wrightia tinctoria* | 2.68 | 3.28 | 3.96 | 9.92 | 3.25 |
| 36 | *Ziziphus mauritiana* | 0.82 | 1.64 | 0.21 | 2.67 | 2.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

**4.1.1.2. Species composition and vegetation structure of Melechavadiyoor Plantation**

A total of 334 trees belonging to 30 species were recorded (Table 4). Of which *Albizia amara* recorded the highest abundance (9.60) followed by *Eucalyptus tereticornis* (6.00) and *Wrightia tinctoria* (5.50). An abundance value of one was recorded for 10 tree species.

Structural analysis indicated that *Albizia amara* recorded the maximum relative density (28.74) followed by *Eucalyptus tereticornis* (17.96). Lowest values were recorded for seven species including *Tamarindus indica, Sterculia guttata* and

*Pongamia pinnata* (0.30). Relative frequency was highest *for Albizia amara* and *Eucalyptus tereticornis* (9.17), whereas nine species recorded relative frequency value less than one.

Relative basal area was worked out to be highest for *Albizia amara* (30.54) and lowest for *Tamarindus indica* (0.05). Similarly studies revealed that highest IVI was observed in *Albizia amara* (9.6) and lowest for *Tamarindus indica* (1.27).

#### 4.1.1.3. Species composition and vegetation structure of Palliyara Plantation

This plantation had a total of 277 individuals belonging to 31 different species. Structural analysis in Palliyara plantation showed that performance of *Leucaena leucocephala*, a fast growing exotic species with highest abundance (9.63), relative density (69.49), relative frequency (9.64), relative basal area (33.183) and IVI (112.32). All the quantitative parameters were higher values for this species in Palliyara plantation (Table 5).

Relative density of *Albizia amara, Wrightia tinctoria* recorded a value of 41.52 and 21.66 respectively. *Acacia polycantha, Albizia amara* observed an abundance of 6.00 and 5.75 respectively and 15 species recorded least abundance value of one. IVI values also shown similar trend 60.44 and 35.89, species such *Cordia monoica, Manilkara zapota, Pleiospermium alatum* recorded least values for relative density, relative frequency, relative basal area and IVI.

Table 4. Structural analysis of vegetation in Melechavadiyoor Plantation at Attappady

| Sl No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia spp* | 0.30 | 0.92 | 0.53 | 1.75 | 1.00 |
| 2 | *Acacia ferruginea* | 1.50 | 3.67 | 0.87 | 6.03 | 1.25 |
| 3 | *Acacia planifrons* | 0.30 | 0.92 | 0.32 | 1.53 | 1.00 |
| 4 | *Albizia amara* | 28.74 | 9.17 | 30.54 | 68.46 | 9.60 |
| 5 | *Azadirachta indica* | 2.99 | 5.50 | 4.33 | 12.83 | 1.67 |
| 6 | *Bauhinia racemosa* | 0.60 | 0.92 | 0.76 | 2.28 | 2.00 |
| 7 | *Erythroxylum monogynum* | 5.39 | 6.42 | 5.55 | 17.36 | 2.57 |
| 8 | *Chloroxylon swietenia* | 6.29 | 7.34 | 2.67 | 16.30 | 2.63 |
| 9 | *Givotia molluccana* | 0.60 | 1.83 | 1.42 | 3.86 | 1.00 |
| 10 | *Dichrostachys cinerea* | 0.90 | 2.75 | 1.64 | 5.29 | 1.00 |
| 11 | *Diospyros cordifolia* | 6.29 | 7.34 | 5.58 | 19.21 | 2.63 |
| 12 | *Eucalyptus grandis* | 1.50 | 2.75 | 3.42 | 7.66 | 1.67 |
| 13 | *Eucalyptus tereticornis* | 17.96 | 9.17 | 19.01 | 46.15 | 6.00 |
| 15 | *Gmelina arborea* | 0.30 | 0.92 | 1.17 | 2.39 | 1.00 |
| 16 | *Holoptelea integrifolia* | 1.80 | 4.59 | 6.32 | 12.70 | 1.20 |
| 17 | *Commiphora berryi* | 2.10 | 3.67 | 0.55 | 6.31 | 1.75 |
| 18 | *Radermachera xylocarpa* | 0.60 | 0.92 | 0.36 | 1.88 | 2.00 |
| 19 | *Grewia hirsuta* | 0.30 | 0.92 | 0.39 | 1.61 | 1.00 |
| 20 | *Pleiospermium alatum* | 2.69 | 4.59 | 2.76 | 10.04 | 1.80 |
| 21 | *Mundulea sericea* | 2.99 | 2.75 | 1.68 | 7.43 | 3.33 |
| 22 | *Premna mollissima* | 0.60 | 1.83 | 0.29 | 2.72 | 1.00 |
| 23 | *Murraya koenigii* | 0.60 | 1.83 | 0.54 | 2.97 | 1.00 |
| 24 | *Pongamia pinnata* | 0.30 | 0.92 | 0.15 | 1.37 | 1.00 |
| 25 | *Sapindus emarginatus* | 5.69 | 6.42 | 2.86 | 14.97 | 2.71 |
| 26 | *Sterculia guttata* | 0.30 | 0.92 | 0.18 | 1.39 | 1.00 |
| 27 | *Strychnos potatorum* | 2.69 | 3.67 | 1.22 | 7.59 | 2.25 |
| 28 | *Tamarindus indica* | 0.30 | 0.92 | 0.05 | 1.27 | 1.00 |
| 29 | *Fluggea virosa* | 2.10 | 4.59 | 2.52 | 9.21 | 1.40 |
| 30 | *Wrightia tinctoria* | 3.29 | 1.83 | 2.23 | 7.35 | 5.50 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

Table 5. Structural analysis of vegetation in Palliyara Plantation at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia sps.* | 6.32 | 3.61 | 2.255 | 12.19 | 2.33 |
| 2 | *Acacia planifrons* | 0.90 | 1.20 | 0.498 | 2.61 | 1.00 |
| 3 | *Acacia polycantha* | 16.25 | 3.61 | 16.029 | 35.89 | 6.00 |
| 4 | *Albizia amara* | 41.52 | 9.64 | 9.285 | 60.44 | 5.75 |
| 5 | *Albizia procera* | 2.71 | 2.41 | 1.824 | 6.94 | 1.50 |
| 6 | *Annona squamosa* | 1.81 | 1.20 | 0.188 | 3.20 | 2.00 |
| 7 | *Manilkara zapota* | 0.90 | 1.20 | 0.034 | 2.14 | 1.00 |
| 8 | *Azadirachta indica* | 15.34 | 9.64 | 2.208 | 27.19 | 2.13 |
| 9 | *Bombax ceiba* | 0.90 | 1.20 | 1.120 | 3.23 | 1.00 |
| 10 | *Cassia fistula* | 0.90 | 1.20 | 0.896 | 3.00 | 1.00 |
| 11 | *Commiphora caudata* | 0.90 | 1.20 | 0.251 | 2.36 | 1.00 |
| 12 | *Dichrostachys cinerea* | 2.71 | 2.41 | 0.516 | 5.63 | 1.50 |
| 13 | *Diospyros cordifolia* | 8.12 | 3.61 | 0.472 | 12.21 | 3.00 |
| 14 | *Gmelina arborea* | 2.71 | 2.41 | 0.547 | 5.66 | 1.50 |
| 15 | *Trewia nudiflora* | 1.81 | 2.41 | 0.397 | 4.61 | 1.00 |
| 16 | *Grevillea robusta* | 0.90 | 1.20 | 0.138 | 2.25 | 1.00 |
| 17 | *Grewia tiliifolia* | 0.90 | 1.20 | 0.112 | 2.22 | 1.00 |
| 18 | *Holoptelea integrifolia* | 14.44 | 4.82 | 3.111 | 22.37 | 4.00 |
| 19 | *Jacaranda mimosifolia* | 2.71 | 2.41 | 2.724 | 7.84 | 1.50 |
| 20 | *Pleiospermium alatum* | 0.90 | 1.20 | 0.050 | 2.16 | 1.00 |
| 21 | *Leucaena leucocephala* | 69.49 | 9.64 | 33.183 | 112.32 | 9.63 |
| 22 | *Pterocarpus marsupium* | 0.90 | 1.20 | 0.310 | 2.42 | 1.00 |
| 23 | *Santalum album* | 0.90 | 1.20 | 0.152 | 2.26 | 1.00 |
| 24 | *Senna siamea* | 0.90 | 1.20 | 0.398 | 2.51 | 1.00 |
| 25 | *Simarauba glauca* | 4.51 | 3.61 | 0.558 | 8.69 | 1.67 |
| 26 | *Strychnos nux-vomica* | 0.90 | 1.20 | 0.112 | 2.22 | 1.00 |
| 27 | *Strychnos potatorum* | 11.73 | 4.82 | 1.050 | 17.60 | 3.25 |
| 28 | *Tamarindus indica* | 11.73 | 8.43 | 10.793 | 30.96 | 1.86 |

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 29 | *Terminalia bellirica* | 2.71 | 3.61 | 0.299 | 6.62 | 1.00 |
| 30 | *Cordia monoica* | 0.90 | 1.20 | 0.042 | 2.15 | 1.00 |
| 31 | *Wrightia tinctoria* | 21.66 | 6.02 | 10.448 | 38.13 | 4.80 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

#### 4.1.1.4. Species composition and vegetation structure of Pattimalam Plantation

Structural analysis of this plantation revealed the presence of total 303 individuals belonging to 22 different species (Table 6). *Mundulea sericea* had highest relative density (29.70) followed by *Leucaena leucocephala* (24.42) and *Albizia amara* (11.55). The lowest relative density was observed in six species including *Cassine paniculata, Commiphora berryi* and *Phyllanthus emblica* (0.33). The maximum abundance was recorded for *Mundulea sericea* (12.86) followed by *Leucaena leucocephala* (10.57) and *Chloroxylon swietenia* (5.50).

Highest relative frequency was for *Albizia amara, Leucaena leucocephala* and *Mundulea sericea* (10.77), the least relative frequency was observed in eight species. *Albizia amara* (44.97) showed the highest relative basal area followed by *Leucaena leucophloea* (26.64) and *Mundulea sericea* (26.64), whereas the lowest relative basal area was recorded for *Cordia monoica* (0.04).

Highest IVI was observed in *Albizia amara* (67.29) followed by *Leucaena leucocephala* (61.83). The lowest IVI was observed by *Murraya koenigii* and *Cordia monoica* (1.90).

#### 4.1.1.5. Species composition and vegetation structure of Sambarcode Plantation

In total 351 individuals belonging to 30 different species were recorded for Sambarcode plantation (Table 7). The studies revealed that highest relative density (23.08) was recorded for *Chloroxylon swietenia* followed by *Leucaena leucocephala* (19.66). Highest abundance was recorded for *Leucaena leucocephala* (11.50) followed by *Chloroxylon swietenia* (10.13).

Highest relative frequency was observed for *Chloroxylon swietenia* (9.20), whereas lowest (1.15) was observed for ten species. Relative basal area was recorded highest for *Leucaena leucocephala* (49.24) followed by *Chloroxylon swietenia* (16.56), whereas lowest value was obtained for species such as *Anogeissus latifolia* (0.03), *Albizia procera, Sapindus emarginatus and Tamarindus indica* (0.04). Maximum IVI was observed for *Leucaena leucocephala* (75.79) followed by *Chloroxylon swietenia* (48.83) and *Azadirachta indica* (23.24), the lowest IVI (1.47) was recorded for *Anogeissus latifolia* and *Cordia monoica.*

Table 6. Structural analysis of vegetation in Pattimalam Plantation at Attappady

| Sl No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia leucophloea* | 1.98 | 3.08 | 0.93 | 5.99 | 3.00 |
| 2 | *Acacia planifrons* | 1.98 | 4.62 | 2.26 | 8.85 | 2.00 |
| 3 | *Albizia amara* | 11.55 | 10.77 | 44.97 | 67.29 | 5.00 |
| 4 | *Azadirachta indica* | 1.32 | 3.08 | 0.35 | 4.75 | 2.00 |
| 5 | *Chloroxylon swietenia* | 10.89 | 9.23 | 8.21 | 28.33 | 5.50 |
| 6 | *Dichrostachys cinerea* | 0.66 | 3.08 | 0.11 | 3.85 | 1.00 |
| 7 | *Diospyros cordifolia* | 5.28 | 9.23 | 1.78 | 16.29 | 2.67 |
| 8 | *Dodonaea viscosa* | 1.32 | 4.62 | 0.30 | 6.23 | 1.33 |
| 9 | *Gmelina arborea* | 4.29 | 9.23 | 3.63 | 17.15 | 2.17 |
| 11 | *Holoptelea integrifolia* | 0.66 | 1.54 | 0.10 | 2.30 | 2.00 |

| Sl No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 12 | *Commiphora berryi* | 0.33 | 1.54 | 0.08 | 1.95 | 1.00 |
| 13 | *Canthium coramandellicum* | 0.33 | 1.54 | 0.05 | 1.92 | 1.00 |
| 15 | *Murraya koenigii* | 0.33 | 1.54 | 0.04 | 1.90 | 1.00 |
| 17 | *Leucaena leucocephala* | 24.42 | 10.77 | 26.64 | 61.83 | 10.57 |
| 18 | *Mundulea sericea* | 29.70 | 10.77 | 8.27 | 48.74 | 12.86 |
| 19 | *Cassine paniculata* | 0.33 | 1.54 | 0.20 | 2.07 | 1.00 |
| 20 | *Phyllanthus emblica* | 0.33 | 1.54 | 0.11 | 1.98 | 1.00 |
| 21 | *Senna auriculata* | 0.99 | 3.08 | 0.19 | 4.25 | 1.50 |
| 22 | *Senna siamea* | 0.99 | 3.08 | 0.27 | 4.34 | 1.50 |
| 23 | *Senna spectablis* | 0.66 | 1.54 | 0.09 | 2.29 | 2.00 |
| 25 | *Cordia monoica* | 0.33 | 1.54 | 0.04 | 1.90 | 1.00 |
| 26 | *Wrightia tinctoria* | 1.32 | 3.08 | 1.40 | 5.79 | 2.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

Table 7. Structural analysis of vegetation in Sambarcode Plantation at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia ferruginea* | 6.27 | 3.45 | 4.34 | 14.06 | 7.33 |
| 2 | *Acacia sps.* | 6.84 | 6.90 | 4.44 | 18.17 | 4.00 |
| 3 | *Albizia lebbeck* | 0.57 | 2.30 | 0.59 | 3.46 | 1.00 |
| 4 | *Albizia procera* | 0.28 | 1.15 | 0.04 | 1.48 | 1.00 |
| 5 | *Anogeissus latifolia* | 0.28 | 1.15 | 0.03 | 1.47 | 1.00 |
| 6 | *Azadirachta indica* | 12.25 | 6.90 | 4.09 | 23.24 | 7.17 |
| 7 | *Caesalpinia sps.* | 0.57 | 2.30 | 1.24 | 4.10 | 1.00 |
| 8 | *Cassia fistula* | 1.14 | 2.30 | 0.73 | 4.16 | 2.00 |
| 9 | *Casuarina eqisetifolia* | 0.28 | 1.15 | 0.23 | 1.67 | 1.00 |
| 10 | *Chloroxylon swietenia* | 23.08 | 9.20 | 16.56 | 48.83 | 10.13 |
| 11 | *Dichrostachys cinerea* | 1.14 | 1.15 | 0.59 | 2.88 | 4.00 |

| Sl No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 12 | *Diospyros cordifolia* | 2.85 | 6.90 | 0.51 | 10.25 | 1.67 |
| 13 | *Givotia moluccana* | 0.28 | 1.15 | 8.46 | 9.89 | 1.00 |
| 14 | *Gmelina arborea* | 3.99 | 6.90 | 1.36 | 12.24 | 2.33 |
| 15 | *Trewia nudiflora* | 0.28 | 1.15 | 0.12 | 1.56 | 1.00 |
| 17 | *Holoptelea integrifolia* | 4.27 | 5.75 | 1.40 | 11.42 | 3.00 |
| 18 | *Jacaranda mimosifolia* | 0.85 | 3.45 | 0.22 | 4.52 | 1.00 |
| 19 | *Leucaena leucocephala* | 19.66 | 6.90 | 49.24 | 75.79 | 11.50 |
| 20 | *Mundulea sericea* | 3.99 | 3.45 | 1.41 | 8.85 | 4.67 |
| 21 | *Naringi crenulata* | 1.99 | 4.60 | 0.73 | 7.32 | 1.75 |
| 22 | *Pongamia pinnata* | 1.14 | 2.30 | 0.51 | 3.95 | 2.00 |
| 23 | *Sapindus emarginatus* | 0.28 | 1.15 | 0.04 | 1.48 | 1.00 |
| 24 | *Prosopis juliflora* | 0.28 | 1.15 | 0.19 | 1.63 | 1.00 |
| 25 | *Senna siamea* | 1.14 | 2.30 | 1.69 | 5.13 | 2.00 |
| 26 | *Simarouba glauca* | 0.57 | 1.15 | 0.22 | 1.94 | 2.00 |
| 27 | *Strychnos potatorum* | 2.85 | 6.90 | 0.41 | 10.16 | 1.67 |
| 28 | *Syzygium cumini* | 0.57 | 2.30 | 0.27 | 3.14 | 1.00 |
| 29 | *Tamarindus indica* | 0.57 | 2.30 | 0.04 | 2.91 | 1.00 |
| 30 | *Flueggea virosa* | 1.42 | 1.15 | 0.21 | 2.78 | 5.00 |
| 31 | *Cordia monoica* | 0.28 | 1.15 | 0.03 | 1.47 | 1.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

#### 4.1.1.6 Species composition and vegetation structure of Vellamari Plantation

A total of 267 trees belonging to 22 species were recorded in Vellamari plantation (Table 8). *Albizia amara* recorded the highest abundance of 13.14. It was followed by *Acacia sps.* (6.00) and *Chloroxylon swietenia* (5.29). *Dodonaea viscosa* recorded lowest abundance of 0.75. *Albizia amara* recorded highest relative density

(34.46), relative frequency (8.97), relative basal area (55.67) and IVI (99.10). *Chloroxylon swietenia* recorded 2nd highest in relative density (13.86), relative frequency (8.97) and IVI (33.37). *Leucaena leucocephala* observed relative basal area of 11.91, *Tectona grandis* and *Pleiospermium alatum* recorded least relative basal area (0.04).

*Pleiospermium alatum, Tectona grandis, Terminalia bellirica* and *Strychnos potatorum* showed lowest relative density (0.37). Similar trend was followed in relative frequency also. Species such as *Pleiospermium alatum, Tectona grandis, Terminalia bellirica, Strychnos potatorum and Canthium coromandelicum* (1.28) had the least. The relative basal area (0.04) and IVI (1.69) were lowest in *Tectona grandis* and *Pleiospermium alatum.*

#### 4.1.1.7 Species composition and vegetation structure of Kottathara Plantation

Kottathara plantation comprised of 176 individuals (Table 9) of GBH > 10cm belonging to 15 different species, *Mundulea sericea* recorded the highest relative density (44.89) followed by *Albizia amara* (18.18) and *Chloroxylon swietenia* (17.05). *Canthium coromandelicum* had the least relative density (0.57). Highest abundance was recorded for *Mundulea sericea* (9.88) followed by *Chloroxylon swietenia* (6.00). The lowest abundance value was obtained for *Naringi crenulata, Canthium coromandelicum* and *Dichrostachys cinerea* (1.00).

Distribution of species in the above plantation area indicated maximum relative frequency for *Albizia amara* and *Mundulea sericea* (19.51), whereas lowest frequency (2.44) was observed in seven species. *Albizia amara* (31.47) had the highest relative basal area followed by *Chloroxylon swietenia* (26.01) and *Mundulea sericea* (15.63). *Canthium coromandelicum* recorded the lowest relative basal area (0.31).Maximum IVI was observed in *Mundulea sericea* (86.02) followed by *Albizia* *amara* (73.20) and *Chloroxylon swietenia* (58.19). The lowest IVI was observed in *Canthium coromandelicum* (3.69).

Table 8. Structural analysis of vegetation in Vellamari Plantation at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia sps.* | 4.49 | 2.56 | 5.19 | 12.24 | 6.00 |
| 2 | *Acacia ferruginea* | 1.50 | 5.13 | 1.13 | 7.75 | 1.00 |
| 3 | *Acacia leucophloea* | 3.37 | 2.56 | 0.97 | 6.91 | 4.50 |
| 4 | *Albizia amara* | 34.46 | 8.97 | 55.67 | 99.10 | 13.14 |
| 5 | *Albizia procera* | 2.62 | 6.41 | 5.25 | 14.28 | 1.40 |
| 6 | *Azadirachta indica* | 4.49 | 6.41 | 1.02 | 11.93 | 2.40 |
| 7 | *Erythroxylum monogynum* | 6.74 | 7.69 | 3.12 | 17.55 | 3.00 |
| 8 | *Chloroxylon swietenia* | 13.86 | 8.97 | 10.54 | 33.37 | 5.29 |
| 9 | *Cassine albens* | 1.12 | 3.85 | 0.99 | 5.96 | 1.00 |
| 10 | *Diospyros cordifolia* | 1.50 | 3.85 | 0.33 | 5.67 | 1.33 |
| 11 | *Dodonaea viscosa* | 1.12 | 5.13 | 0.10 | 6.35 | 0.75 |
| 12 | *Gmelina arborea* | 4.49 | 7.69 | 1.42 | 13.61 | 2.00 |
| 13 | *Canthium coromandelicum* | 0.75 | 1.28 | 0.05 | 2.08 | 2.00 |
| 14 | *Pleiospermium alatum* | 0.37 | 1.28 | 0.04 | 1.69 | 1.00 |
| 15 | *Leucaena leucocephala* | 7.87 | 7.69 | 11.91 | 27.47 | 3.50 |
| 16 | *Mundulea sericea* | 4.12 | 6.41 | 0.65 | 11.18 | 2.20 |
| 17 | *Murraya koenigii* | 2.62 | 3.85 | 0.48 | 6.95 | 2.33 |
| 19 | *Strychnos potatorum* | 0.37 | 1.28 | 0.11 | 1.77 | 1.00 |
| 20 | *Tamarindus indica* | 2.25 | 2.56 | 0.53 | 5.34 | 3.00 |
| 21 | *Tectona grandis* | 0.37 | 1.28 | 0.04 | 1.69 | 1.00 |
| 22 | *Terminalia bellirica* | 0.37 | 1.28 | 0.07 | 1.72 | 1.00 |
| 23 | *Wrightia tinctoria* | 1.12 | 3.85 | 0.41 | 5.38 | 1.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

Table 9. Structural analysis of vegetation in Kottathara Plantation at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia ferruginea* | 1.14 | 2.44 | 1.81 | 5.81 | 2.00 |
| 2 | *Acacia planifrons* | 1.14 | 2.44 | 0.78 | 4.77 | 2.00 |
| 3 | *Albizia amara* | 18.18 | 19.51 | 31.47 | 73.20 | 4.00 |
| 4 | *Erythroxylum monogynum* | 1.70 | 2.44 | 2.13 | 6.73 | 3.00 |
| 5 | *Chloroxylon swietenia* | 17.05 | 12.20 | 26.01 | 58.19 | 6.00 |
| 6 | *Dichrostachys cinerea* | 1.14 | 4.88 | 1.51 | 8.28 | 1.00 |
| 7 | *Diospyros cordifolia* | 3.41 | 12.20 | 4.44 | 21.99 | 1.20 |
| 8 | *Gmelina arborea* | 3.98 | 7.32 | 4.64 | 17.24 | 2.33 |
| 9 | *Canthium coromandelicum* | 0.57 | 2.44 | 0.31 | 3.69 | 1.00 |
| 10 | *Morinda pubescens* | 1.14 | 2.44 | 5.84 | 9.83 | 2.00 |
| 11 | *Mundulea sericea* | 44.89 | 19.51 | 15.63 | 86.02 | 9.88 |
| 12 | *Naringi crenulata* | 1.14 | 4.88 | 0.54 | 7.31 | 1.00 |
| 13 | *Phyllanthus emblica* | 1.14 | 2.44 | 0.61 | 4.61 | 2.00 |
| 14 | *Pongamia pinnata* | 1.14 | 2.44 | 0.86 | 4.86 | 2.00 |
| 15 | *Senna siamea* | 2.27 | 2.44 | 3.43 | 8.65 | 4.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

### 4.1.1.8. Species composition and vegetation structure of Sambarcode BCA

Structural analysis of the BCA area showed that total of 485 individuals belonging to 43 species were present (Table 10). *Chloroxylon swietenia* (9.90) had the highest relative density followed by *Azadirachta indica* (9.69). The lowest value (0.21) was for 11 species. Highest abundance value was recorded for *Dalbergia latifolia* (8.00) followed by *Chloroxylon swietenia* (6.86) and *Azadirachta indica* (6.71). Abundance was lowest for *Holoptelea integrifolia* (0.80).

Relative frequency was highest for two species *Azadirachta indica* and *Chloroxylon swietenia* (5.74), whereas lowest value (0.82) was recorded for 14 species. Relative basal area was recorded highest for *Givotia moluccana* (53.91) followed by *Prosopis juliflora* (6.37), whereas lowest values were shared by *Syzygium cumini*, *Cassia fistula*, *Alamanda cathatrica* (0.01). Highest IVI was recorded for *Givotia moluccana* (64.80) followed by *Chloroxylon swietenia* (20.87) and *Azadirachta indica* (17.96). The lowest IVI was for *Alamanda cathatrica* (1.03).

### 4.1.1.9. Species composition and vegetation structure of Palliyara BCA

Palliyara BCA comprised of 538 individuals belonging to 49 different species (Table 11). The highest relative density worked out to 30.44 for *Santalum album* and 18.63 for *Tectona grandis*. The lowest relative density was recorded in ten species (0.18). Abundance values indicated similar trends as shown by relative density *Santalum album* (20.63) and *Tectona grandis* (14.43) had highest abundance. While, 15 species recorded the least abundance value of one (Table 12).

Highest relative frequency was recorded by three species *Anogeissus latifolia*, *Grewia tiliifolia* and *Santalum album* (6.02). Out of 49 species 19 species had the least relative frequency of 0.75. Relative basal area was estimated and it was observed that maximum value was for *Givotia moluccana* (37.72) followed by

*Tectona grandis* (13.59). The lowest relative basal area was observed for *Annona squamosa, Dodonaea viscosa* and *Pongamia pinnata* (0.02). Importance value index was estimated in the area, highest IVI was recorded in *Santalum album* (46.11) followed by *Givotia moluccana* (41.84) and *Tectona grandis* (37.49). The lowest IVI was recorded in *Pongamia pinnata* and *Annona squamosa* (0.95).

Table 10. Structural analysis of vegetation in Sambarcode BCA at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia ferruginea* | 1.24 | 3.28 | 0.45 | 4.97 | 1.50 |
| 2 | *Acacia sps.* | 0.62 | 1.64 | 0.48 | 2.74 | 1.50 |
| 3 | *Alamanda cathatrica* | 0.21 | 0.82 | 0.01 | 1.03 | 1.00 |
| 4 | *Albizia amara* | 5.77 | 4.10 | 2.10 | 11.97 | 5.60 |
| 5 | *Albizia lebbeck* | 4.33 | 4.10 | 3.77 | 12.20 | 4.20 |
| 6 | *Albizia odoratissima* | 2.47 | 2.46 | 6.34 | 11.27 | 4.00 |
| 7 | *Albizia procera* | 1.65 | 1.64 | 1.29 | 4.58 | 4.00 |
| 8 | *Anogeissus latifolia* | 3.51 | 4.10 | 0.65 | 8.25 | 3.40 |
| 9 | *Azadirachta indica* | 9.69 | 5.74 | 2.53 | 17.96 | 6.71 |
| 10 | *Bauhinia racemosa* | 0.82 | 1.64 | 0.24 | 2.70 | 2.00 |
| 11 | *Cassia fistula* | 0.21 | 0.82 | 0.01 | 1.04 | 1.00 |
| 12 | *Casuarina equisetifolia* | 0.21 | 0.82 | 0.06 | 1.08 | 1.00 |
| 13 | *Chloroxylon swietenia* | 9.90 | 5.74 | 5.24 | 20.87 | 6.86 |
| 14 | *Dalbergia latifolia* | 1.65 | 0.82 | 0.74 | 3.21 | 8.00 |
| 15 | *Dichrostachys cinerea* | 1.86 | 2.46 | 0.40 | 4.71 | 3.00 |
| 16 | *Diospyros cordifolia* | 2.47 | 1.64 | 0.17 | 4.28 | 6.00 |
| 17 | *Givotia moluccana* | 5.98 | 4.92 | 53.91 | 64.80 | 4.83 |
| 18 | *Gmelina arborea* | 1.65 | 2.46 | 0.20 | 4.31 | 2.67 |
| 19 | *Grewia tiliifolia* | 3.30 | 3.28 | 1.28 | 7.86 | 4.00 |
| 20 | *Holoptelea integrifolia* | 0.82 | 4.10 | 0.69 | 5.62 | 0.80 |
| 21 | *Grewia serrulata* | 0.82 | 0.82 | 0.14 | 1.79 | 4.00 |
| 22 | *Leucaena leucophloea* | 1.24 | 1.64 | 0.59 | 3.47 | 3.00 |

| Sl No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 23 | *Sterculia guttata* | 0.82 | 1.64 | 0.17 | 2.63 | 2.00 |
| 24 | *Morinda pubescens* | 0.41 | 0.82 | 0.10 | 1.33 | 2.00 |
| 25 | *Mundulea sericea* | 1.24 | 1.64 | 0.10 | 2.98 | 3.00 |
| 26 | *Murraya koenigii* | 0.21 | 0.82 | 0.02 | 1.04 | 1.00 |
| 27 | *Naringi crenulata* | 0.41 | 0.82 | 0.16 | 1.40 | 2.00 |
| 28 | *Neolamarckia cadamba* | 0.21 | 0.82 | 0.36 | 1.39 | 1.00 |
| 29 | *Stereospermum colais* | 0.21 | 0.82 | 0.07 | 1.10 | 1.00 |
| 30 | *Albizia chinensis* | 0.21 | 0.82 | 0.07 | 1.10 | 1.00 |
| 31 | *Peltophorum pterocarpum* | 5.15 | 4.10 | 2.55 | 11.81 | 5.00 |
| [illegible] | *Phyllanthus emblica* | 2.06 | 2.46 | 0.33 | 4.85 | 3.33 |
| 33 | *Prosopis juliflora* | 4.12 | 2.46 | 6.37 | 12.96 | 6.67 |
| 34 | *Santalum album* | 0.21 | 0.82 | 0.13 | 1.15 | 1.00 |
| 35 | *Senna auriculata* | 4.54 | 3.28 | 1.86 | 9.68 | 5.50 |
| 37 | *Simarouba glauca* | 2.06 | 2.46 | 0.91 | 5.43 | 3.33 |
| 38 | *Strychnos potatorum* | 5.15 | 4.10 | 0.55 | 9.80 | 5.00 |
| 39 | *Syzigium cuminii* | 0.21 | 0.82 | 0.01 | 1.04 | 1.00 |
| 40 | *Tecoma stans* | 0.21 | 0.82 | 0.03 | 1.05 | 1.00 |
| 41 | *Tectona grandis* | 3.30 | 2.46 | 2.20 | 7.96 | 5.33 |
| 42 | *Terminalia bellirica* | 0.62 | 2.46 | 0.06 | 3.14 | 1.00 |
| 43 | *Wrightia tinctoria* | 5.77 | 4.92 | 1.88 | 12.57 | 4.67 |
| 44 | *Ziziphus mauritiana* | 2.47 | 1.64 | 0.43 | 4.54 | 6.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

Table 11. Structural analysis of vegetation in Palliyara BCA at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Acacia planifrons* | 1.29 | 3.01 | 1.51 | 5.81 | 1.75 |
| 2 | *Acacia ferruginea* | 2.58 | 5.26 | 3.31 | 11.16 | 2.00 |
| 3 | *Acacia leucophloea* | 0.37 | 0.75 | 2.19 | 3.31 | 2.00 |
| 4 | *Albizia chinensis* | 0.18 | 0.75 | 0.03 | 0.97 | 1.00 |
| 5 | *Albizia amara* | 0.55 | 0.75 | 0.42 | 1.72 | 3.00 |
| 6 | *Albizia lebbeck* | 2.21 | 1.50 | 2.28 | 6.00 | 6.00 |
| 7 | *Albizia odoratissima* | 0.92 | 2.26 | 1.03 | 4.21 | 1.67 |
| 8 | *Albizia procera* | 0.18 | 0.75 | 0.19 | 1.13 | 1.00 |
| 9 | *Annona squamosa* | 0.18 | 0.75 | 0.02 | 0.95 | 1.00 |
| 10 | *Anogeissus latifolia* | 7.38 | 6.02 | 6.07 | 19.46 | 5.00 |
| 11 | *Azadirachta indica* | 1.66 | 2.26 | 4.69 | 8.61 | 3.00 |
| 12 | *Bauhinia racemosa* | 0.37 | 0.75 | 0.04 | 1.16 | 2.00 |
| 13 | *Bombax ceiba* | 0.55 | 2.26 | 0.16 | 2.97 | 1.00 |
| 14 | *Bridelia retusa* | 0.18 | 0.75 | 0.03 | 0.97 | 1.00 |
| 15 | *Cassia fistula* | 0.55 | 1.50 | 0.27 | 2.33 | 1.50 |
| 16 | *Dalbergia latifolia* | 0.37 | 1.50 | 0.09 | 1.96 | 1.00 |
| 17 | *Givotia moluccana* | 1.11 | 3.01 | 37.72 | 41.84 | 1.50 |
| 18 | *Dichrostachys cinerea* | 1.29 | 2.26 | 0.36 | 3.91 | 2.33 |
| 19 | *Diospyros cordifolia* | 1.29 | 2.26 | 0.64 | 4.19 | 2.33 |
| 20 | *Dodonaea viscosa* | 0.18 | 0.75 | 0.02 | 0.96 | 1.00 |
| 21 | *Pleiospermium alatum* | 0.18 | 0.75 | 0.03 | 0.97 | 1.00 |
| 22 | *Gmelina arborea* | 0.74 | 1.50 | 0.11 | 2.35 | 2.00 |
| 23 | *Trewia nudiflora* | 0.18 | 0.75 | 0.04 | 0.97 | 1.00 |
| 24 | *Grevillea robusta* | 0.92 | 2.26 | 0.16 | 3.34 | 1.67 |
| 25 | *Grewia tiliifolia* | 3.87 | 6.02 | 2.19 | 12.08 | 2.63 |
| 26 | *Holoptelea integrifolia* | 0.37 | 0.75 | 0.17 | 1.29 | 2.00 |
| 27 | *Schefflera wallichiana* | 0.74 | 0.75 | 0.20 | 1.69 | 4.00 |
| 28 | *Sterculia guttata* | 0.55 | 0.75 | 0.25 | 1.55 | 3.00 |

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 29 | *Catunaregam spinosa* | 0.18 | 0.75 | 0.28 | 1.22 | 1.00 |
| 30 | *Leucaena leucocephala* | 0.37 | 0.75 | 0.11 | 1.23 | 2.00 |
| 31 | *Grewia spp.* | 0.18 | 0.75 | 0.03 | 0.97 | 1.00 |
| 32 | *Morinda pubescens* | 1.11 | 2.26 | 1.16 | 4.53 | 2.00 |
| 33 | *Murraya koenigii* | 0.37 | 1.50 | 0.06 | 1.93 | 1.00 |
| 34 | *Cassine paniculata* | 2.03 | 3.76 | 0.83 | 6.62 | 2.20 |
| 35 | *Naringi crenulata* | 0.92 | 2.26 | 0.31 | 3.49 | 1.67 |
| 36 | *Phyllanthus emblica* | 1.11 | 2.26 | 0.16 | 3.53 | 2.00 |
| 37 | *Pongamia pinnata* | 0.18 | 0.75 | 0.02 | 0.95 | 1.00 |
| 38 | *Pterocarpus marsupium* | 2.95 | 1.50 | 1.92 | 6.38 | 8.00 |
| 39 | *Santalum album* | 30.44 | 6.02 | 9.65 | 46.11 | 20.63 |
| 40 | *Simarouba glauca* | 1.48 | 2.26 | 1.67 | 5.40 | 2.67 |
| 41 | *Stereospermum colais* | 1.11 | 1.50 | 0.35 | 2.96 | 3.00 |
| 42 | *Strychnos potatorum* | 1.66 | 4.51 | 0.51 | 6.68 | 1.50 |
| 43 | *Syzygium cumini* | 0.55 | 1.50 | 0.07 | 2.13 | 1.50 |
| 44 | *Tamarindus indica* | 0.37 | 1.50 | 0.04 | 1.91 | 1.00 |
| 45 | *Tectona grandis* | 18.63 | 5.26 | 13.59 | 37.49 | 14.43 |
| 46 | *Diospyros melanoxylon* | 0.18 | 0.75 | 0.07 | 1.00 | 1.00 |
| 47 | *Wrightia tinctoria* | 0.55 | 1.50 | 0.06 | 2.11 | 1.50 |
| 48 | *Zanthoxylum rhetsa* | 0.55 | 0.75 | 3.55 | 4.86 | 3.00 |
| 49 | *Ziziphus mauritiana* | 3.32 | 3.01 | 1.17 | 7.50 | 4.50 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

### 4.1.1.10. Species composition and vegetation structure of Kottathara BCA

In total 335 individuals belonging to 22 different species were recorded over a 4000 $m^2$ sampling area (Table 12). Floristic study revealed that relative density was highest for *Albizia amara* (31.04) followed by *Azadirachta indica* (23.78) and the least relative density was for *Holoptelea integrifolia, Tamarindus indica* and *Ziziphus mauritiana* (0.30). *Albizia amara, Azadirachta indica, Diospyros cordifolia and Mundulea sericea* had the highest relative frequency of 1.54. The lowest relative frequency (1.54) was observed in *Holoptelea integrifolia, Tamarindus indica, Tectona grandis and Sapindus emarginatus.*

Relative basal area was recorded highest for *Albizia amara* (67.56) followed by *Azadirachta indica* (15.18) and the lowest for *Ziziphus mauritana* (0.03). Imporatance value index was maximum for *Albizia amara* (107.83) followed by *Azadirachta indica* (49.18) and the lowest for *Ziziphus mauritana* (1.87).

Table 12. Structural analysis of vegetation in Kottathara BCA at Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| 1 | *Albizia amara* | 31.04 | 9.23 | 67.56 | 107.83 | 17.33 |
| 2 | *Albizia procera* | 1.19 | 4.62 | 1.17 | 6.98 | 1.33 |
| 3 | *Azadirachta indica* | 24.78 | 9.23 | 15.18 | 49.18 | 13.83 |
| 4 | *Grewia hirsuta* | 0.60 | 3.08 | 0.35 | 4.02 | 1.00 |
| 5 | *Erythroxylum monogynum* | 7.76 | 7.69 | 1.96 | 17.42 | 5.20 |
| 6 | *Chloroxylon swietenia* | 0.90 | 4.62 | 0.30 | 5.81 | 1.00 |
| 7 | *Diospyros cordifolia* | 8.06 | 9.23 | 2.44 | 19.73 | 4.50 |
| 8 | *Dodonaea viscosa* | 2.69 | 3.08 | 0.40 | 6.16 | 4.50 |
| 9 | *Gmelina arborea* | 6.87 | 7.69 | 2.52 | 17.07 | 4.60 |
| 10 | *Holoptelea integrifolia* | 0.30 | 1.54 | 0.10 | 1.94 | 1.00 |
| 11 | *Commiphora berryi* | 1.79 | 3.08 | 0.56 | 5.43 | 3.00 |
| 12 | *Canthium coromandelicum* | 1.49 | 3.08 | 0.15 | 4.72 | 2.50 |
| 13 | *Leucaena leucocephala* | 2.39 | 4.62 | 0.94 | 7.94 | 2.67 |
| 14 | *Mundulea sericea* | 1.79 | 9.23 | 0.30 | 11.33 | 1.00 |
| 15 | *Prosopis juliflora* | 1.19 | 3.08 | 0.40 | 4.67 | 2.00 |
| 16 | *Sapindus emarginatus* | 0.60 | 1.54 | 0.98 | 3.12 | 2.00 |
| 17 | *Senna siamea* | 2.09 | 4.62 | 2.28 | 8.99 | 2.33 |
| 18 | *Strychnos potatorum* | 1.19 | 3.08 | 0.22 | 4.49 | 2.00 |
| 19 | *Tamarindus indica* | 0.30 | 1.54 | 1.14 | 2.98 | 1.00 |
| 20 | *Tectona grandis* | 0.90 | 1.54 | 0.82 | 3.26 | 3.00 |
| 21 | *Flueggea virosa* | 1.79 | 3.08 | 0.18 | 5.05 | 3.00 |
| 22 | *Ziziphus mauritiana* | 0.30 | 1.54 | 0.03 | 1.87 | 1.00 |

RD-Relative density, RF- Relative frequency, RBA-Relative basal area, IVI-Importance value index, A- Abundance

#### 4.1.1.11. Species composition and vegetation structure of non ecorestored areas

In Vellamari non eco-restored area, total of 38 individuals belonging to 4 species were identified. *Albizia amara* had the highest IVI (134.08), relative density (31.58), relative basal area (77.5), and abundance (4.00). *Mundulea sericea* had the highest frequency (33.33). The least relative density (15.79), relative frequency (16.67) and relative basal area (4.89) were recorded in *Senna auriculata*. The lowest IVI and abundance were observed in *Mundulea sericea*, 64.95 and 2.25 respectively (Table 13).

Kottathara area consists of total 20 individuals of 5 species. *Albizia amara* had the highest IVI (112.52), relative density (34.78), relative basal area (77.5), and abundance (4.00). *Diospyros cordifolia* had the highest frequency (30.77). The least relative density (4.35), abundance (1.00), relative basal area (1.15) and IVI (13.19) were recorded in *Senna auriculata*. The lowest relative frequency was observed in *Mundulea sericea*, and *Chloroxylon swietenia* (7.69).

In Melechavadiyoor area, total 21 individuals in which highest relative basal area (60.30) and IVI (122.20) were observed in *Albizia amara*, while highest relative density (42.86), relative frequency (33.33) and abundance (3.00) were shown by *Gliricidia sepium*. *Azadirachta indica* showed the lowest value.

Palliyara recorded total 19 individuals belonging to six species. *Naringa crenulata* had the highest relative density, relative frequency, relative basal area, abundance and IVI. Relative density was lowest for *Tectona grandis* (31.26) and lowest relative basal area for *Pterocarpus marsupium* (7.70). IVI observed for *Tectona grandis* was least (31.26).

In Pattimalam area only three species were found *Tamarindus indica* observed the highest relative basal area (85.82), abundance (3.00) and IVI (148.32). *Gmelina arborea* observed highest relative density and relative frequency (50).

Table 13. Structural analysis of Various Non Ecorestored Areas (NER) of Attappady

| Sl. No | Species | RD | RF | RBA | IVI | A |
|---|---|---|---|---|---|---|
| **Vellamari** | | | | | | |
| 1 | *Albizia amara* | 31.58 | 25 | 77.50 | 134.08 | 4.00 |
| 2 | *Dodonaea viscosa* | 28.95 | 25 | 9.69 | 63.64 | 3.67 |
| 3 | *Mundulea sericea* | 23.68 | 33.33 | 7.93 | 64.95 | 2.25 |
| 4 | *Senna auriculata* | 15.79 | 16.67 | 4.89 | 37.34 | 3.00 |
| **Kottathara** | | | | | | |
| 1 | *Mundulea sericea* | 13.04 | 23.08 | 3.81 | 39.93 | 1.00 |
| 2 | *Albizia amara* | 34.78 | 15.38 | 62.36 | 112.52 | 4.00 |
| 3 | *Chloroxylon swietenia* | 13.04 | 7.69 | 16.74 | 37.48 | 3.00 |
| 4 | *Diospyros cordifolia* | 21.74 | 30.77 | 5.94 | 58.45 | 1.25 |
| 5 | *Senna auriculata* | 4.35 | 7.69 | 1.15 | 13.19 | 1.00 |
| **Melechavadiyoor** | | | | | | |
| 1 | *Albizia amara* | 28.57 | 33.33 | 60.30 | 122.20 | 2.00 |
| 2 | *Azadirachta indica* | 9.52 | 11.11 | 2.10 | 22.73 | 2.00 |
| 3 | *Gliricidia sepium* | 42.86 | 33.33 | 19.00 | 95.19 | 3.00 |
| 4 | *Prosopis juliflora* | 19.05 | 22.22 | 18.61 | 59.88 | 2.00 |
| **Palliyara** | | | | | | |
| 1 | *Albizia lebbeck* | 21.05 | 25 | 12.27 | 58.32 | 1.33 |
| 2 | *Strychnos potatorum* | 10.53 | 8.33 | 15.70 | 34.56 | 2.00 |
| 3 | *Tectona grandis* | 5.26 | 8.33 | 17.67 | 31.26 | 1.00 |
| 4 | *Pterocarpus marsupium* | 10.53 | 16.67 | 7.70 | 34.89 | 1.00 |
| 5 | *Naringa crenulata* | 31.58 | 25 | 30.15 | 86.73 | 2.00 |
| 6 | *Anacardium occidentale* | 21.05 | 16.67 | 16.51 | 54.23 | 2.00 |
| **Pattimalam** | | | | | | |
| 1 | *Gmelina arborea* | 50 | 50 | 8.44 | 108.44 | 2.00 |
| 2 | *Tamarindus indica* | 37.5 | 25 | 85.82 | 148.32 | 3.00 |
| 3 | *Albizia amara* | 12.5 | 25 | 5.74 | 43.24 | 1.00 |

An attempt was made to do a hierarchical cluster analysis of the plantation BCA and NER based on species composition and density. The analysis used Chi-square measure for classification. The Dendrogram of the classification given in Figure 2. It was observed that Palliyara BCA was the most distant from the rest of study area. At a cluster distance of 20 units 3 clusters were identified. Palliyara and Sambarcode BCA separated from the rest of the sample. At a cluster distance of 15 units Kottathara BCA and Sambarcode plantation too seperated. At a cluster distance of 10 unit Palliyara and Melechavadiyoor plantation also separated, While at a cluster of 10 units all non ecorestored area were grouped together with Pattimalam, Vellamari and Kottathara plantations. At a cluster distance of 5 units it was observed that all the non ecorestored remain together as a single cluster. While the BCA and plantation area completely separated out.

The principal component analysis was done to find the association among plantation, BCA and NER based distribution of 15 abundant species composition and density in the aboveground vegetation (Fig. 3). From the graph it was observed that all BCA's were distant from the origin. While the plantations were clustered together near to the origin. Kottathara BCA, Sambarcode and Melechavadiyoor plantations were found in the same quadrats, while all the NER'a were found in the opposite quadrats. The sites such as Sambarcode and Palliyara BCA, as well as the Agali plantaion were clustered within a quadrat, Vellamari, Pattimalam and Kottathara plantation were grouped together in the opposite quadrat. *Erythroxylum monogynum*, *Albizia amara*, *Gmelina arborea*, *Diospyros cordifolia* and *Azadirachta indica* were commonly seen in Kottathara BCA, Sambarcode and Melechavadiyoor plantations. While *Mundulea sericea* was found in drier tracts of Vellamari, Pattimalam and Kottathara plantations. *Leucaena leucocephala* was commonly found in most of the study sites. The most prominent species were absent from the non ecorestored regions.

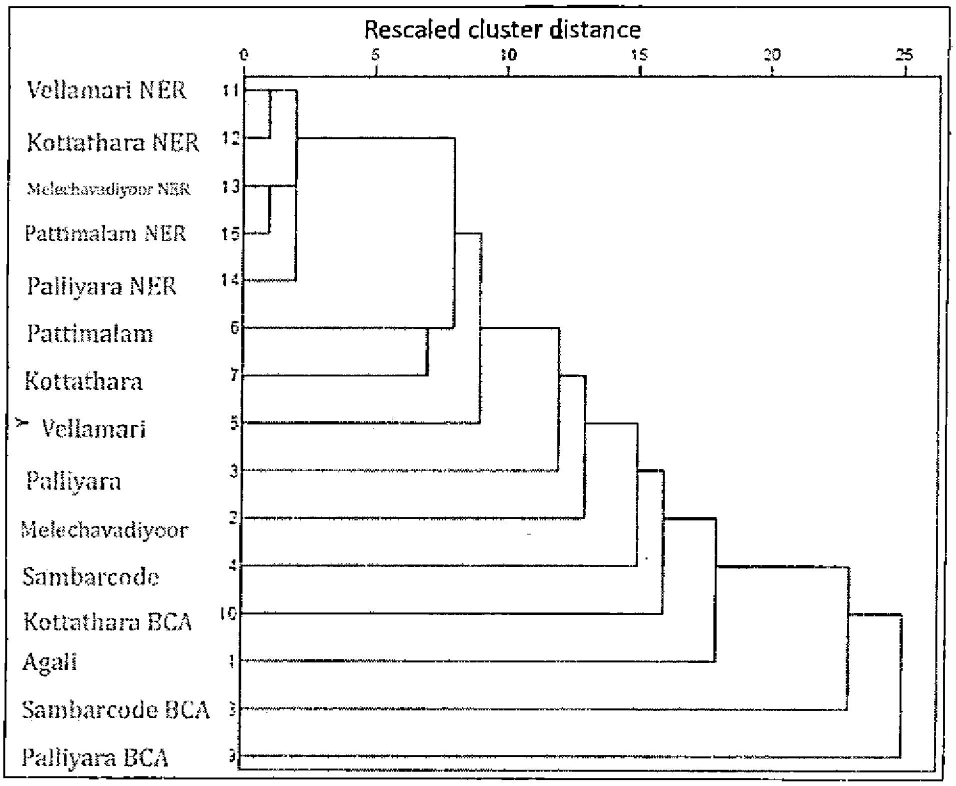



Fig. 2. Dendrogram of aboveground vegetation in Eastern Attappady

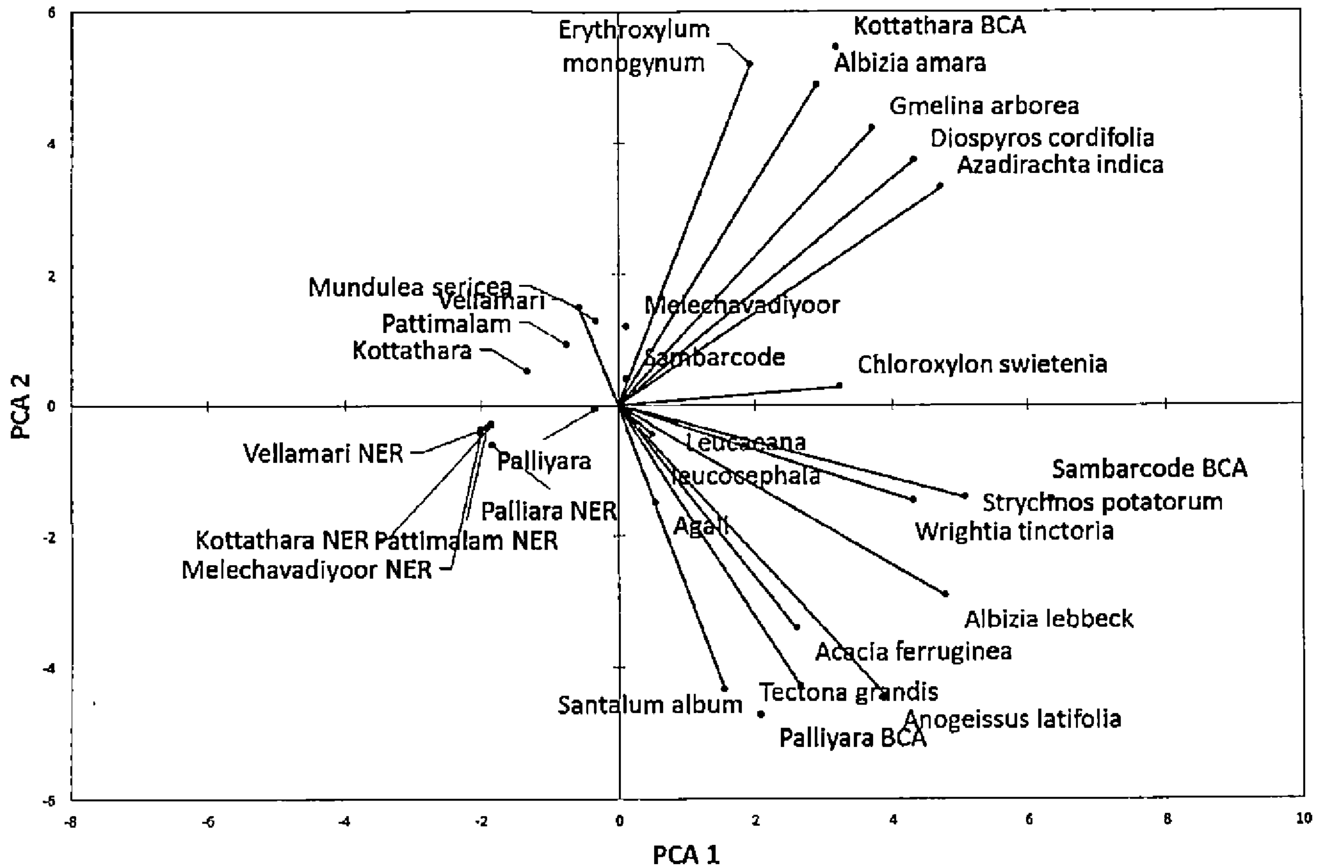



Fig. 3. PCA bi-plot of East Attappady vegetation with respect to species

### 4.1.2. Floristic diversity of vegetation in eastern Attappady

Location wise floristic diversity of vegetation obtained from the study is presented in Table 14. Among plantations, Simpson's index and concentration of dominance for Sambarcode plantation was 0.88 and 0.12, this was the highest among plantations. The Kottathara plantation had a Simpson's index of 0.73 and Cd 0.27, this was the highest among plantations. Palliyara and Melechavadiyoor plantation had Simpson's index of 0.87 and Cd 0.13. For Agali and Vellamari plantation had Simpson index 0.85 and Cd 0.15. Pattimalam recorded the lowest value for Simpson's index of 0.83 and Cd 0.17.

Shannon Weiner index was recorded highest for Agali plantation (3.92). This plantation had $H_{max}$ (5.32) and Equitability (0.74). Whereas Kottathara plantation observed least Shannon Weiner index (2.53), $H_{max}$ (3.91) and equitability (0.65) (Fig. 4).

In BCA area, highest Simpson's index was observed for Sambarcode BCA (0.95) and its concentration of dominance was 0.05. For Palliyara and Kottathara BCA Simpson's index were 0.86 and 0.83. Sambarcode BCA recorded highest Shannon Weiner index (4.77). The Shannon Wiener index, $H_{max}$ and Equitability for Sambarcode BCA were 4.77, 5.46, 0.87; for Palliyara 3.97, 5.67, 0.70 and for Kottathara 3.26, 4.58 and 0.71 (Fig. 5).

In non ecorestored area, Simpson's index was highest for Palliyara with 0.79 and its Cd 0.21, whereas the lowest Simpson's index was observed for Pattimalam 0.59 and Cd 0.41. The highest Shannon Wiener index recorded in Palliyara plantation (2.38), its $H_{max}$ and Equitability was 2.58 and 0.92 respectively. Box plot analysis of Simpson's index for above ground vegetation was done (Fig. 6). BCA had the highest Simpson index, while the variation was lowest in plantations. Box plots of Shannon-Weiner index also revealed that BCA was the highest, while NER was the lowest (Fig. 7). Kottathara plantation was found to be an outlier in the box plots.

Table 14. Location wise floristic diversity of trees in Eastern Attappady

| Name of the locality | Simpsons Index | Cd | Shannon Weiner index | H max | Equitability (E) |
|---|---|---|---|---|---|
| Plantation | | | | | |
| Agali | 0.85 | 0.15 | 3.92 | 5.32 | 0.74 |
| Melechavadiyoor | 0.87 | 0.13 | 3.70 | 5.00 | 0.74 |
| Palliyara | 0.87 | 0.13 | 3.64 | 4.95 | 0.73 |
| Pattimalam | 0.83 | 0.17 | 3.18 | 4.70 | 0.68 |
| Sambarcode | 0.88 | 0.12 | 3.67 | 4.95 | 0.74 |
| Vellamari | 0.85 | 0.15 | 3.51 | 4.64 | 0.76 |
| Kottathara | 0.73 | 0.27 | 2.53 | 3.91 | 0.65 |
| Biomass Conservation Area | | | | | |
| Palliyara | 0.86 | 0.14 | 3.97 | 5.67 | 0.70 |
| Sambarcode | 0.95 | 0.05 | 4.77 | 5.46 | 0.87 |
| Kottathara | 0.83 | 0.17 | 3.26 | 4.58 | 0.71 |
| Non Ecorestored Area | | | | | |
| Vellamari | 0.74 | 0.26 | 1.96 | 2.00 | 0.98 |
| Kottathara | 0.78 | 0.22 | 2.36 | 2.58 | 0.91 |
| Melechavadiyoor | 0.69 | 0.31 | 1.82 | 2.00 | 0.91 |
| Palliyara | 0.79 | 0.21 | 2.38 | 2.58 | 0.92 |
| Pattimalam | 0.59 | 0.41 | 1.41 | 1.58 | 0.89 |

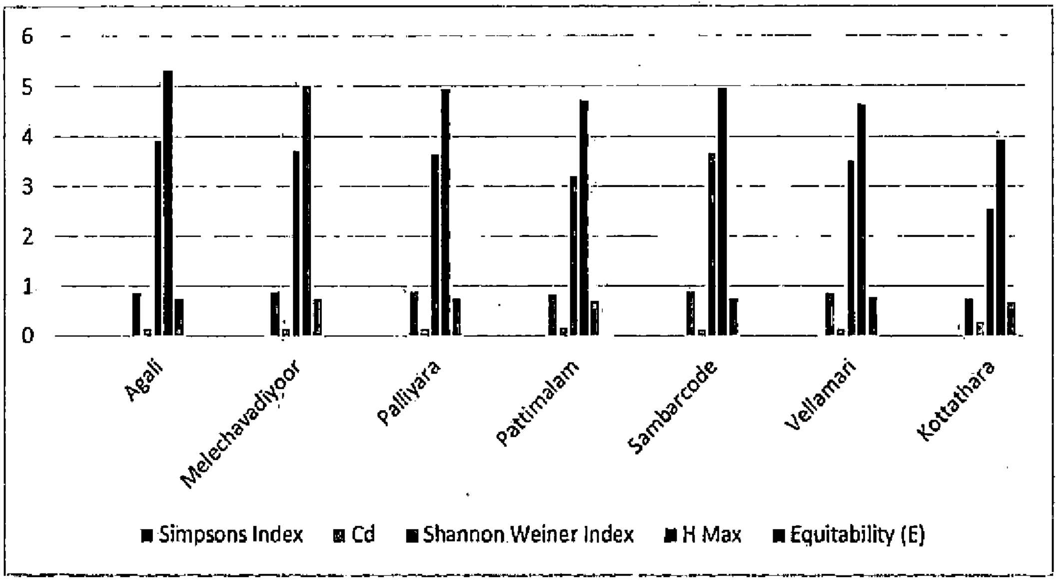



Fig. 4. Floristic diversity indices of various study sites in plantation area

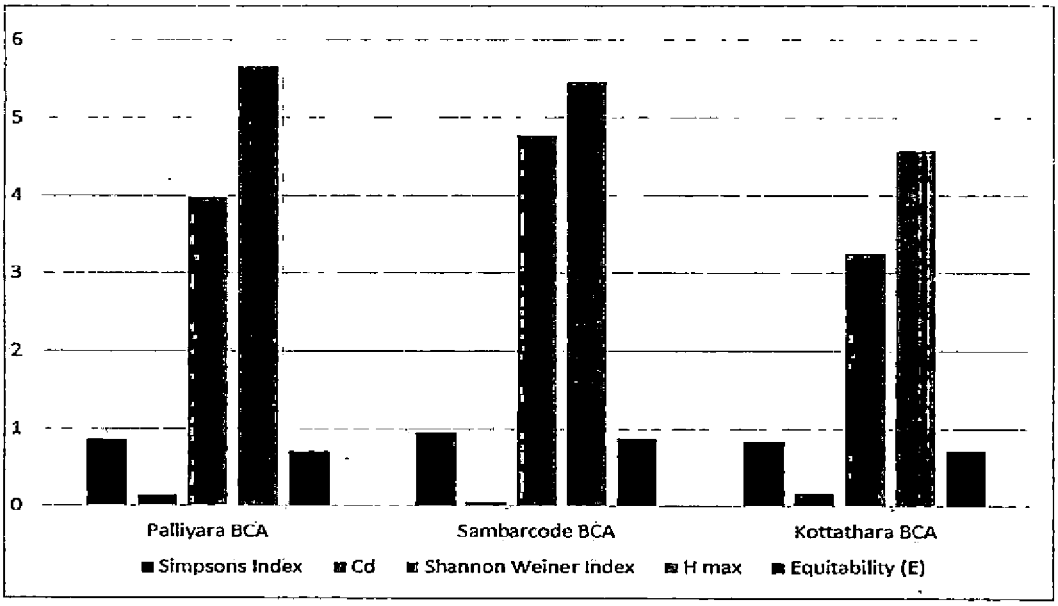



Fig. 5. Floristic diversity indices of various study sites in BCA area

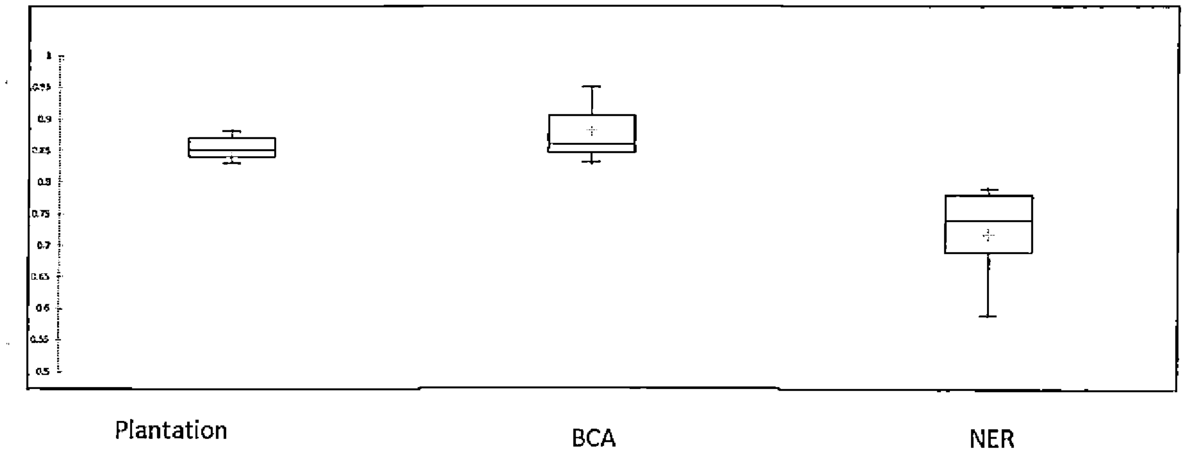



Fig. 6. Simpson's diversity indices for various study sites in Eastern Attappady

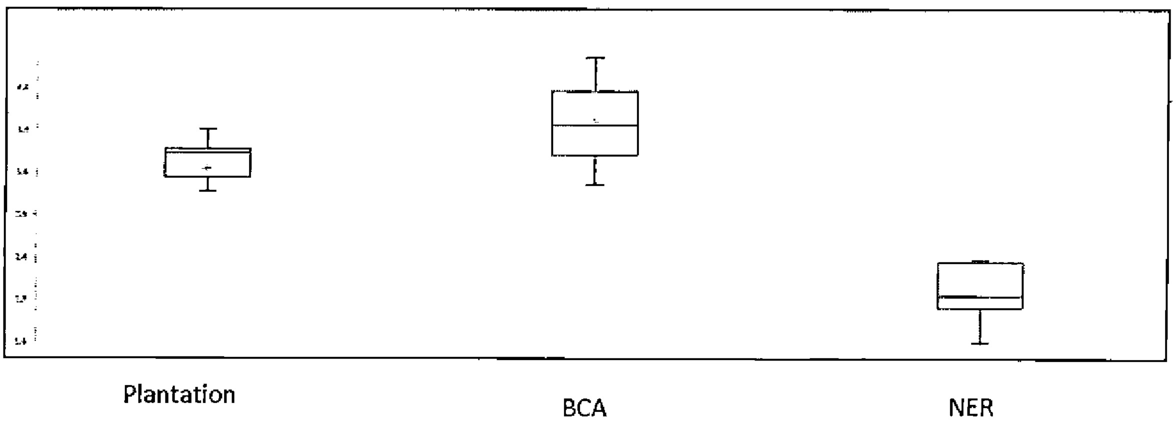



Fig. 7. Shannon-Weiner diversity indices for various study sites in Eastern Attappady

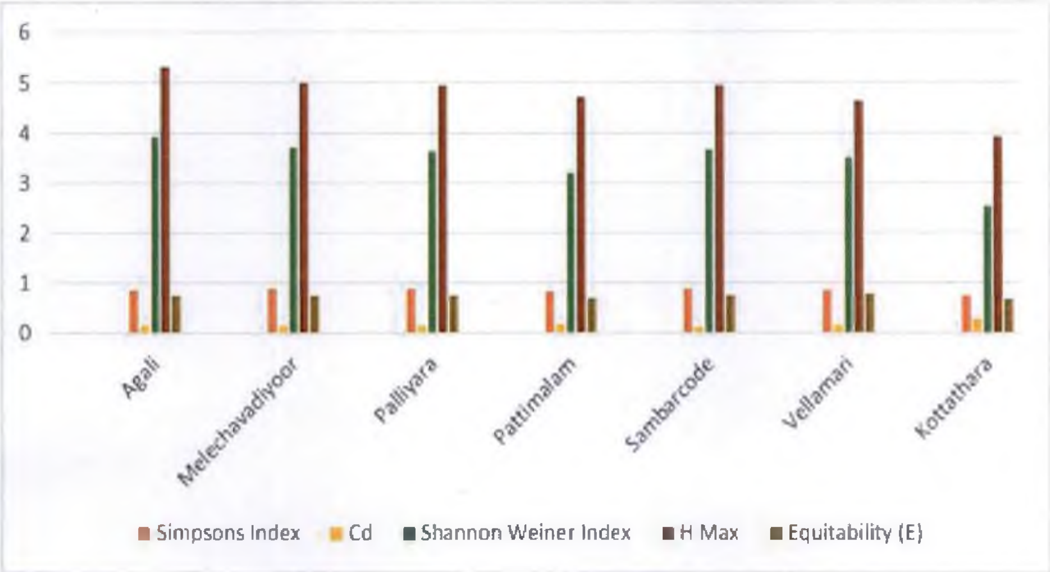



Fig. 4. Floristic diversity indices of various study sites in plantation area

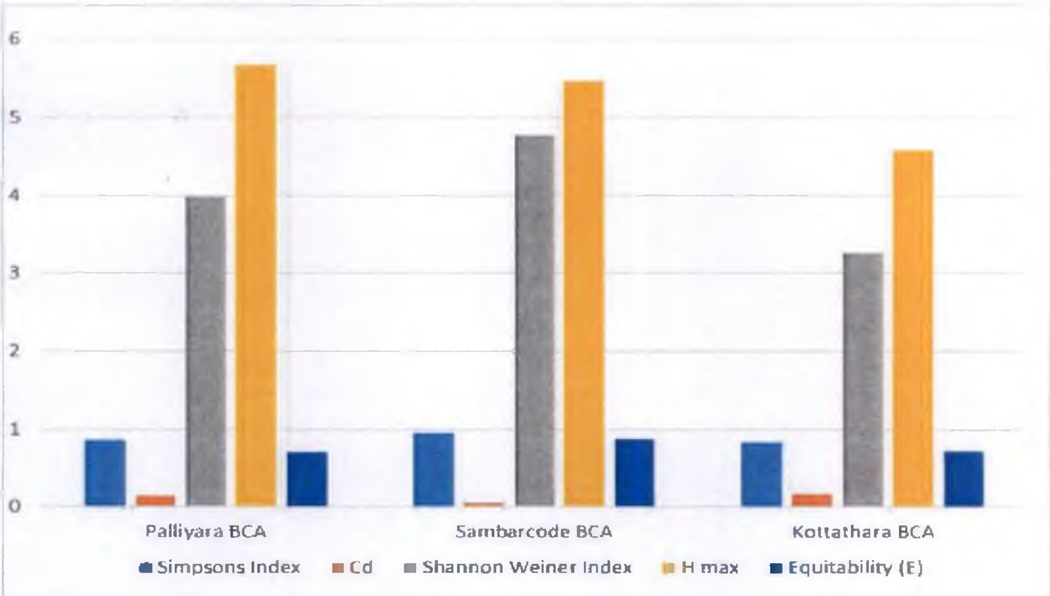



Fig. 5. Floristic diversity indices of various study sites in BCA area

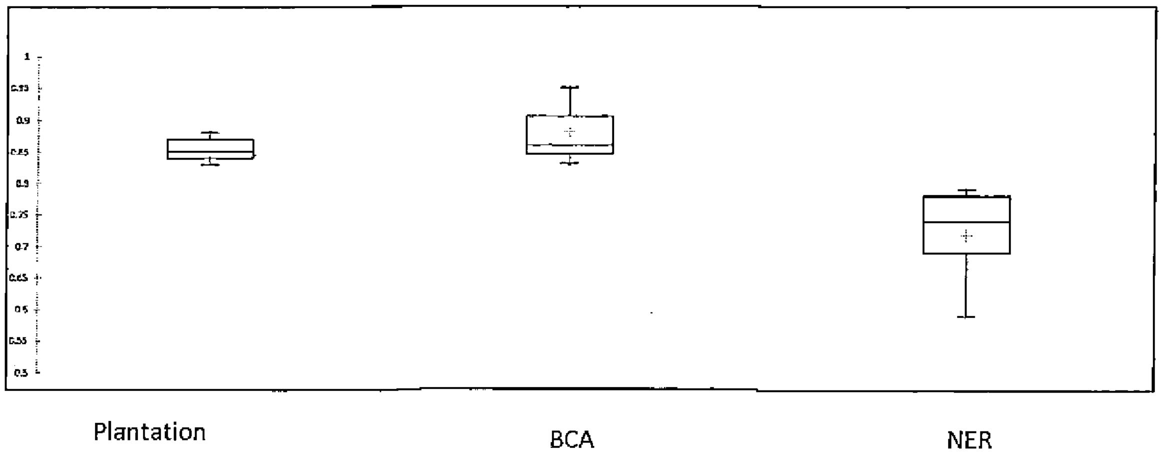



Fig. 6. Simpson's diversity indices for various study sites in Eastern Attappady

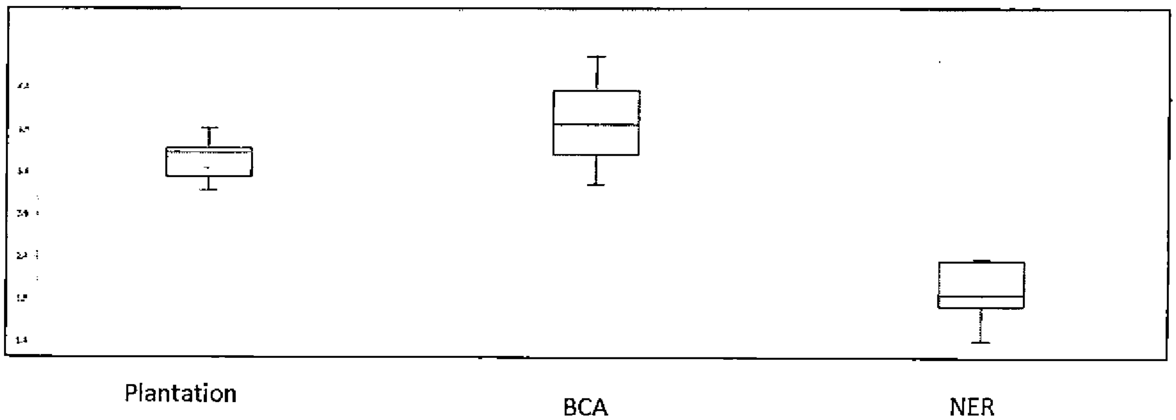



Fig. 7. Shannon-Weiner diversity indices for various study sites in Eastern Attappady

## 4.2. REGENERATION STUDIES

### 4.2.1. Species composition of regeneration in the study area

#### 4.2.1.1. Plantation

In Vellamari plantation, *Leucaena leucocephala* (11.67) had the most abundant regeneration followed by *Dodonaea viscosa* (10.00), the relative density also followed similar trend in which the values were 31.67 and 22.62 (Table 15).

In the case of Melechavadiyoor plantation *Catunaregam spinosa* recorded highest relative density (17.32) and abundance (11), whereas seven species recorded the least relative density of 0.79 and abundance (1.00). In Palliyara plantation *Leucaena leucocephala* (63.13) was the most abundant regeneration followed by *Diospyros cordifolia* (1.92), the relative density was observed maximum for *Leucaena leucocephala* (88.29). The least abundance of 0.82 and relative density of 1.00 were observed for four species.

*Albizia amara* had highest relative density (27.05) and abundance (11.00) in Pattimalam plantation followed by *Mundulea sericea* (25.41) and *Leucaena leucocephala* (15.57). The least abundance (1.00) and relative density (0.85) were shown by *Acacia ferruginea, Acacia planifrons, Cordia monoica, Holoptelea integrifolia* and *Murraya koenigii*.

In Sambarcode plantation highest relative density (73.42) and abundance (41.43) were recorded for *Leucaena leucocephala* followed by *Chloroxylon swietenia* 9.62 and 7.60. *Annona squamosa, Holoptelea integrifolia, Pleiospermium* *alatum* and *Tamarindus indica* recorded the least relative density (0.25) and abundance (1.00).

*Leucaena leucocephala* recorded highest abundance (56.57) and relative density (68.87) in Agali plantation followed by *Santalum album* (9.22 and 10.6). *Tamarindus indica* recorded the least abundance (1.00) and relative density (0.17). The most abundant species in Kottathara plantation was *Albizia amara (*20.41) followed by *Pongamia pinnata* and *Senna siamea* (20.00). The least abundant species was *Dichrostachys cinerea* 1.67. The highest relative density was recorded for *Acacia planifrons* (53.98) followed by *Mundulea sericea (*28.03). The lowest relative density (0.38) was shared by *Naringi crenulata* and *Phyllanthus emblica.*

Total regeneration in plantation accounts to 2540 regenerations belonging to 45 species from sampling area of 1050 $m^2$. The most abundant of it was *Leucaena leucocephala* (179.13), *Albizia amara* (46.74) and *Senna siamea* (31.00).

**4.2.1.2. Biomass area**

In Palliyara BCA, *Santalum album* recorded highest relative density (30.13) and abundance (17.63) followed by *Ziziphus mauritiana* (20.03, 11.75) and *Dodonaea viscosa* (7.26, 11.33) (Table 16). *Pongamia pinnata, Psidium guajava, Grevillea robusta and Dalbergia latifolia* had the lowest relative density and abundance values 0.21 and 1.00.

In the case of Sambarcode BCA, *Leucaena leucocephala* had the highest relative density of 45.39 followed by *Chloroxylon. swietenia* 15.5. Abundance also followed similar trend with values 25.6 and 14.33 respectively. The least abundance (1.00) and relative density (0.35) were shown by *Diospyros cordifolia, Holoptelea integrifolia, Terminalia bellirica* and *Wrightia tinctoria.*

In Kottathara BCA, regeneration studies revealed that *Azadirachta indica* had highest relative density (28.89) and abundance (13.00) followed by *Leucaena leucocephala* (24.44 and 8.8). The lowest relative density and abundance were recorded by *Tamarindus indica* (0.7 and 2).

Total regeneration in three biomass area was 950 seedlings belonging to 51 species. The most abundant of it was *Leucaena leucocephala* (42.4), *Ziziphus mauritiana* (21.25) and *Azadirachta indica* (20.69).

Table 15: Relative density (RD %) and Abundance (A) for regeneration in Plantation Area

| Sl. No | Species | Vellamari | | Melechavadiyoor | | Palliyara | | Pattimalam | | Sambarcode | | Agali | | Kottathara | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | RD | A | RD | A | RD | A | RD | A | RD | A | RD | A | RD | A |
| 1 | *Acacia ferruginea* | | | 0.79 | 1.00 | | | 0.82 | 1.0 | | | | | | |
| 2 | *Acacia leucophloea* | 1.81 | 4.00 | | | | | 1.64 | 2.0 | | | | | | |
| 3 | *Acacia planifrons* | | | | | | | 0.82 | 1.0 | | | | | 53.9 | 1.75 |
| 4 | *Albizia amara* | 9.05 | 6.67 | 15.75 | 3.33 | 1.05 | 3.00 | 27.0 | 11.0 | 1.77 | 2.33 | | | 1.33 | 20.4 |
| 5 | *Albizia procera* | | | | | 1.4 | 8.00 | | | | | | | | |
| 6 | *Annona squamosa* | | | | | | | | | 0.25 | 1.00 | | | | |
| 7 | *Azadirachta indica* | 5.88 | 4.33 | 0.79 | 1.00 | 0.52 | 1.50 | | | 2.28 | 1.80 | 0.52 | 1.50 | | |
| 8 | *Bauhinia racemosa* | | | 0.79 | 1.00 | | | | | | | 1.22 | 3.50 | | |
| 9 | *Bombax cieba* | | | | | | | | | | | 1.22 | 3.50 | | |
| 10 | *Canthium coromandelicum* | 2.71 | 3.00 | | | 0.17 | 1.00 | | | | | | | | |
| 11 | *Cassia fistula* | | | | | | | | | | | 0.52 | 3.00 | | |
| 12 | *Catunaregam spinosa* | | | 17.32 | 11.00 | | | | | | | | | 2.27 | 3.00 |
| 13 | *Ceiba pentandra* | | | | | 0.17 | 1.00 | | | | | | | | |
| 14 | *Chloroxylon swietenia* | 5.88 | 4.33 | | | | | 4.92 | 2.00 | 9.62 | 7.60 | | | 8.71 | 6.57 |
| 15 | *Commiphora berryi* | | | 3.15 | 2.00 | | | | | | | | | | |
| 16 | *Commiphora caudata* | | | | | 0.17 | 1.00 | | | | | | | | |
| 17 | *Cordia monoica* | | | | | | | 0.82 | 1.00 | | | | | 0.95 | 2.50 |
| 18 | *Cordia wallichii* | | | | | 0.17 | 1.00 | | | | | | | | |
| 19 | *Dichrostachys cinerea* | | | 0.79 | 1.00 | 0.17 | 1.00 | | | | | | | 0.95 | 1.67 |
| 20 | *Diospyros cordifolia* | | | 3.15 | 1.00 | 1.92 | 2.75 | 9.02 | 2.75 | 1.27 | 2.50 | 4.35 | 8.33 | 1.33 | 2.33 |
| 21 | *Dodonaea viscosa* | 22.6 | 10.0 | | | | | 2.46 | 1.50 | | | | | | |
| 22 | *Erythroxylum monogynum* | 3.17 | 2.33 | 14.17 | 3.60 | | | | | | | | | | |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | *Flueggea virosa* | | | 7.87 | 10.00 | | | | | | | | | | |
| 24 | *Givotia molluccana* | | | 0.79 | 1.00 | | | | | | | | | | |
| 25 | *Gmelina arborea* | 3.62 | 2.67 | 3.15 | 4.00 | | | 4.1 | 2.50 | 4.05 | 3.20 | | | | |
| 26 | *Grewia hirsuta* | | | 2.36 | 1.00 | | | | | | | | | | |
| 27 | *Grewia tiliifolia* | | | | | 0.35 | 2.00 | | | | | | | | |
| 28 | *Holoptelea integrifolia* | | | 0.79 | 1.00 | 1.57 | 2.25 | 0.82 | 1.00 | 0.25 | 1.00 | 0.35 | 2.00 | | |
| 29 | *Jacaranda mimosifolia* | | | | | 0.52 | 3.00 | | | | | | | | |
| 30 | *Leucaena leucocephala* | 31.67 | 11.67 | | | 88.29 | 63.13 | 15.57 | 6.33 | 73.42 | 41.43 | 68.87 | 56.57 | | |
| 31 | *Mundulea sericea* | 8.6 | 4.75 | 10.24 | 6.50 | | | 25.41 | 4.43 | | | | | 28.03 | 14.80 |
| 32 | *Murraya koenigii* | 4.07 | 2.25 | 7.87 | 5.00 | | | 0.82 | 1.00 | | | | | | |
| 33 | *Naringi crenulata* | | | | | | | | | 0.51 | 2.00 | 2.09 | 6.00 | 0.38 | 2.00 |
| 34 | *Phyllanthus emblica* | | | | | | | | | | | 0.35 | 2.00 | 0.38 | 2.00 |
| 35 | *Pleiospermium alatum* | | | 3.15 | 1.00 | 0.17 | 1.00 | | | 0.25 | 1.00 | 1.04 | 6.00 | | |
| 36 | *Pongamia pinnata* | | | | | 0.35 | 2.00 | | | 1.01 | 1.33 | | | 0.57 | 20.00 |
| 37 | *Santalum album* | | | | | | | | | | | 9.22 | 10.6 | | |
| 38 | *Sapindus emarginatus* | | | 3.94 | 1.00 | | | | | | | | | | |
| 39 | *Senna auriculata* | 0.9 | 2.00 | | | | | 3.28 | 2.00 | | | | | | |
| 40 | *Senna siamea* | | | | | | | 2.46 | 3.00 | 0.76 | 3.00 | 0.87 | 5.00 | 1.14 | 20.0 |
| 41 | *Simarouba glauca* | | | | | | | | | 0.76 | 3.00 | | | | |
| 42 | *Strychnos potatorum* | | | | | 1.4 | 2.67 | | | 1.27 | 1.67 | 0.7 | 4.00 | | |
| 43 | *Tamarindus indica* | | | | | 0.7 | 2.00 | | | 0.25 | 1.00 | 0.17 | 1.00 | | |
| 44 | *Wrightia tinctoria* | | | 0.79 | 1.00 | | | | | | | 0.87 | 5.00 | | |
| 45 | *Ziziphus mauritiana* | | | 2.36 | 1.00 | 0.87 | 2.50 | | | 2.28 | 3.00 | 7.65 | 7.33 | | |

Table 16. Relative density (RD %) and Abundance (A) for regeneration in Biomass area

| Sl. No | Species | Palliyara | | Sambarcode | | Kottathara | |
|---|---|---|---|---|---|---|---|
| | | RD | A | RD | A | RD | A |
| 1 | *Acacia ferruginea* | 0.64 | 3 | | | | |
| 2 | *Acacia leucophloea* | 0.64 | 3 | 3.9 | 11 | | |
| 3 | *Acacia planifrons* | 2.14 | 2.5 | | | | |
| 4 | *Albizia amara* | | | 1.77 | 2.5 | 2.78 | 2.5 |
| 5 | *Albizia lebbeck* | 1.28 | 3 | | | | |
| 6 | *Albizia procera* | 0.43 | 2 | | | | |
| 7 | *Annona squamosa* | 0.43 | 2 | | | | |
| 8 | *Anogeissus latifolia* | 2.14 | 3.33 | 1.06 | 3 | | |
| 9 | *Azadirachta indica* | | | 2.84 | 7.69 | 28.89 | 13 |
| 10 | *Bombax cieba* | 2.56 | 3 | 1.06 | 3 | | |
| 11 | *Bridelia retusa* | 1.71 | 2 | | | | |
| 12 | *Canthium coromandellicum* | | | 1.42 | 4 | 2.78 | 2.5 |
| 13 | *Cassia fistula* | 1.28 | 3 | | | | |
| 14 | *Chloroxylon swietenia* | 0.43 | 2 | 15.25 | 14.33 | | |
| 15 | *Commiphora berryi* | | | | | 2.22 | 2.5 |
| 16 | *Dalbergia latifolia* | 0.21 | 1 | | | | |
| 17 | *Dichrostachys cinerea* | 1.28 | 3 | 1.42 | 2 | | |
| 18 | *Diospyros cordifolia* | | | 0.35 | 1 | 6.11 | 3.67 |
| 19 | *Dodonaea viscosa* | 7.26 | 11.33 | | | 5 | 4.5 |
| 20 | *Erythroxylum monogynum* | | | | | 7.78 | 3.5 |
| 21 | *Flueggea virosa* | | | | | 3.33 | 3 |
| 22 | *Givotia moluccana* | 0.64 | 3 | 1.06 | 3 | | |
| 23 | *Gmelina arborea* | | | 4.96 | 7 | 1.11 | 2 |
| 24 | *Grevillea robusta* | 0.21 | 1 | | | | |
| 25 | *Grewia serrulata* | | | 1.42 | 4 | | |
| 26 | *Grewia tiliifolia* | 2.14 | 2.5 | 2.84 | 8 | | |
| 27 | *Holoptelea integrifolia* | | | 0.35 | 1 | | |

| Sl. No | Species | Palliyara | | Sambarcode | | Kottathara | |
|---|---|---|---|---|---|---|---|
| | | RD | A | RD | A | RD | A |
| 28 | *Leucaena leucocephala* | 3.42 | 8 | 45.39 | 25.6 | 24.44 | 8.8 |
| 29 | *Morinda pubescens* | 0.43 | 2 | | | 9.44 | 3.4 |
| 30 | *Murraya koenigii* | 2.35 | 11 | | | | |
| 31 | *Naringi crenulata* | | | 0.71 | 2 | | |
| 32 | *Phyllanthus emblica* | 2.78 | 4.33 | | | | |
| 33 | *Pleiospermium alatum* | | | 0.71 | 2 | | |
| 34 | *Pongamia pinnata* | 0.21 | 1 | | | | |
| 35 | *Psidium guajava* | 0.21 | 1 | | | | |
| 36 | *Pterocarpus marsupium* | 1.71 | 8 | | | | |
| 37 | *Santalum album* | 30.13 | 17.63 | | | | |
| 38 | *Sapindus emarginatus* | 0.43 | 2 | | | | |
| 39 | *Schefflera wallichiana* | 2.35 | 5.5 | 1.77 | 2.5 | | |
| 40 | *Senna auriculata* | | | 3.19 | 9 | | |
| 41 | *Senna siamea* | | | | | 2.22 | 4 |
| 42 | *Simarouba glauca* | 0.64 | 3 | | | | |
| 43 | *Sterculia guttata* | | | 1.06 | 3 | | |
| 44 | *Strychnos potatorum* | 0.43 | 2 | 2.13 | 2 | 1.67 | 3 |
| 45 | *Syzygium cuminii* | 0.43 | 2 | | | | |
| 46 | *Tamarindus indica* | 3.85 | 3.6 | | | 0.56 | 1 |
| 47 | *Tectona grandis* | 3.63 | 3.4 | | | | |
| 48 | *Terminalia bellirica* | | | 0.35 | 1 | | |
| 49 | *Wrightia tinctoria* | 0.85 | 2 | 0.35 | 1 | | |
| 50 | *Ziziphus mauritiana* | 20.03 | 11.75 | 4.61 | 6.5 | 1.67 | 3 |

An attempt was made to do a hierarchical cluster analysis of the plantation, BCA and non ecorestored area based on species composition and density of regeneration. The analysis used Chi-square measure for classification. The Dendrogram of the classification is given in Figure 8. At a cluster distance of 25 it was found that Sambarcode, Palliyara, Agali plantations and Sambarcode BCA formed a cluster distant from the rest. At a cluster mark of 15 Palliyara BCA and Kottathara plantation were separated out from the rest. All non ecorestored area along with Pattimalam and Vellamari plantation formed a single cluster at a cluster distance of 10. The Non ecorestored area of Palliyara was distinct and separated from the rest. Kottathara BCA and Melechavadiyoor plantation too deviated fom this main cluster.

PCA analysis was done for regenerations of the most prominent tree species in the study area (Fig. 9). Kottathara and Pattimalam plantation and Sambarcode BCA was found in a quadrat. In that Kottathara plantation was placed distant from the origin. The species diversity was highest for Kottathara plantation which comprised of species like *Albizia amara*, *Mundulea sericea* and *Chloroxylon swietenia*. Agali and Sambarcode plantation formed another quadrat. Agali plantation had lower species diversity even though it had higher abundance of individuals per species. *Diospyros cordifolia*, *Leucaena leucocephala*, *Ziziphus mauritiana* and *Santalum album* were predominantly regenerated in the Sambarcode and Agali plantations. All the non-eco-restored areas clustered closer to the origin and *Dodonaea viscosa* had higher chance of occurrence in these regions.

### 4.2.2. Floristic diversity of regeneration in eastern Attappady

The floristic diversity of tree regeneration was assessed location wise (Table 17). The table reveals that highest Simpsons index among plantation was recorded in Melechavadiyoor (0.89) followed by Vellamari (0.86), Pattimalam (0.85) and Kottathara (0.60). The lowest Simpson index was recorded in Palliyara plantation (0.12). Shannon Weiner index also followed similar trend with

Melechavadiyoor (3.60) followed by Vellamari (3.25) and Pattimalam (3.21). $H_{max}$ and equitability recorded highest for Melechavadiyoor 4.46 and 0.81.

Among BCA areas, highest Simpson's index was shared by Palliyara and Kottathara with a value of 0.86 and the least by Sambarcode BCA (0.75). Shannon Weiner index for Palliyara was 3.77 followed by Kottathara 3.33 and least for Sambarcode (2.99). $H_{max}$ was highest for Palliyara 5.17 and highest equitability for Kottathara 0.81.

Among non ecorestored area Pattimalam recorded highest Simpson's index of 0.69 and least for Palliyara (0.55) whose concentration of dominance was highest 0.45. Shannon Weiner index followed similar trend with Pattimalam 1.93 and Palliyara 1.35. $H_{max}$ and equitability were observed highest for Pattimalam (2.32) and Vellamari (0.99).

Box plots of Simpson's diversity indices (Fig. 10) indicated highest variation (0.12-0.89) in plantations while it varied only to a small extent in both BCA's (0.75-0.86) and NER's (0.58-0.69). The box plots of Shannon-Weiner indices for regeneration (Fig. 11) also exhibited a similar trend, with the highest variation (0.95-3.60) in plantations and lowest in BCA's (4.09-5.17) and NER's (1.58-2.32).

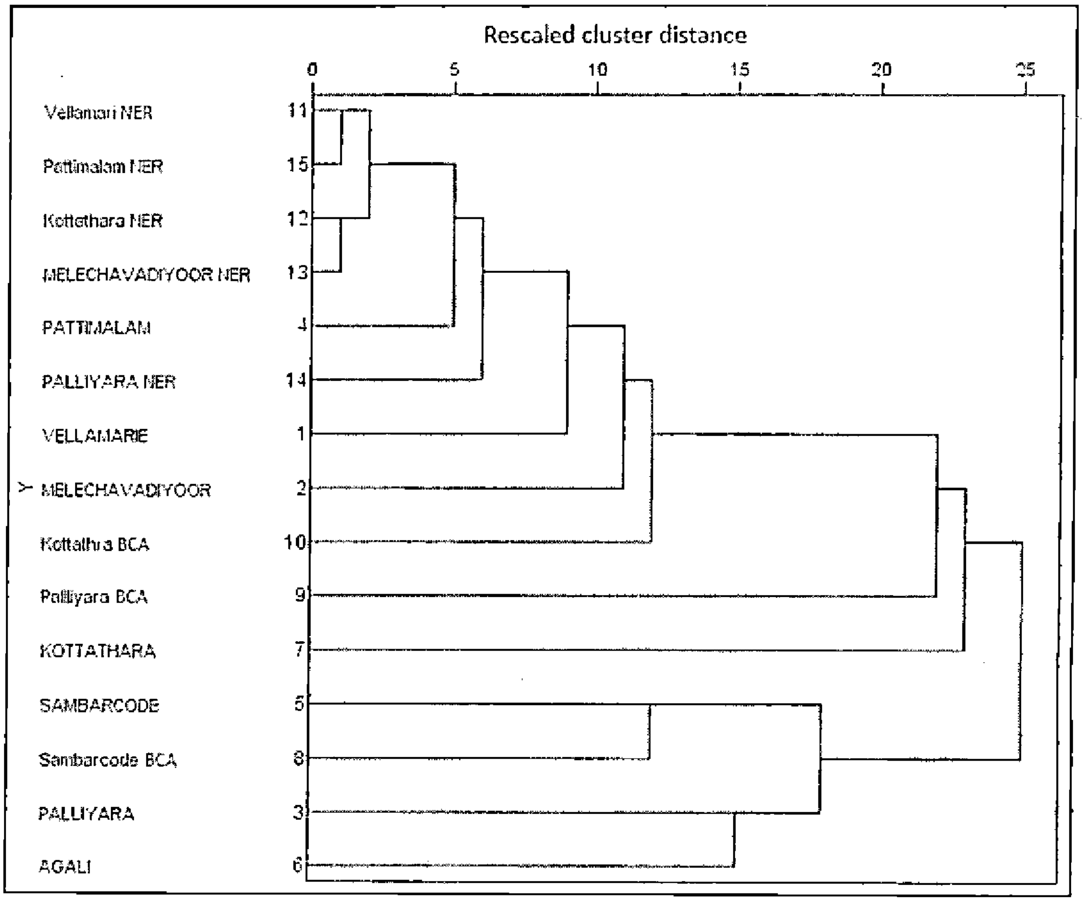



Fig 8. Dendrogram of Regeneration

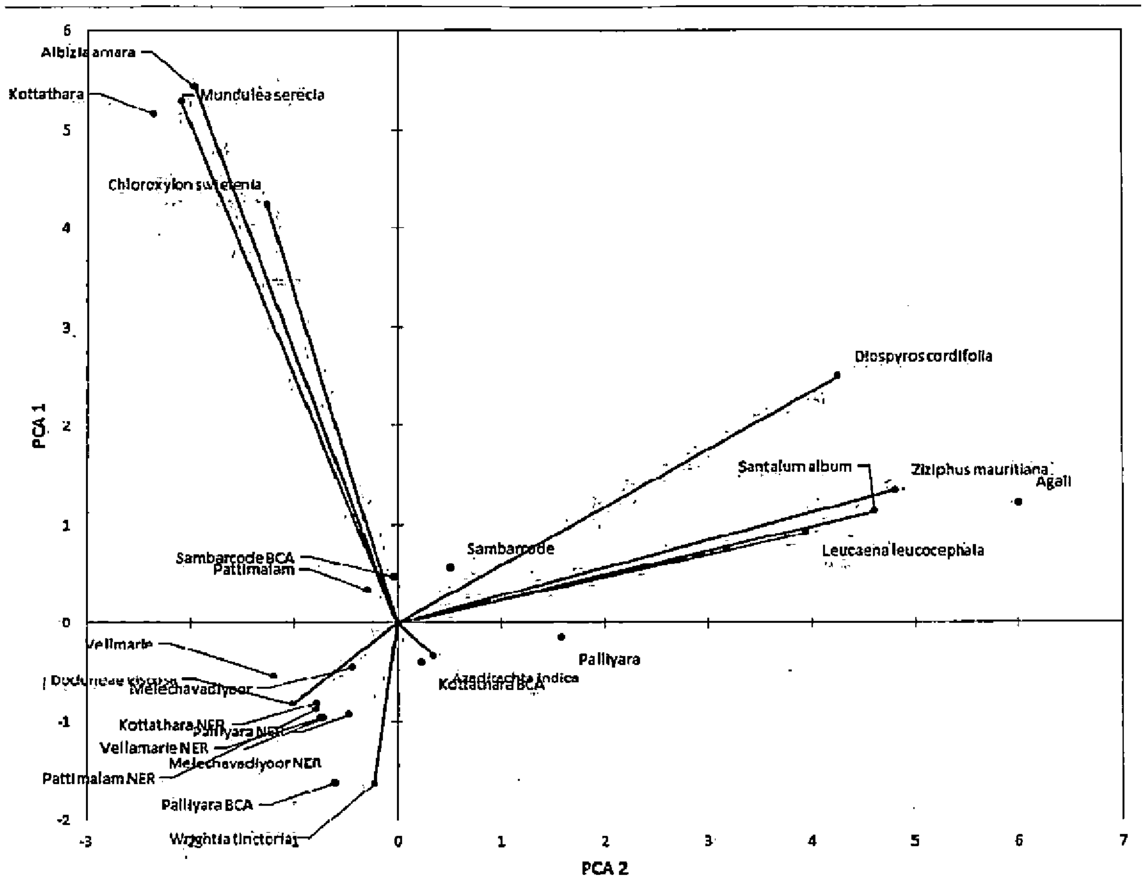



Fig. 9. PCA bi-plot analysis of regeneration with respect to species in Eastern Attappady

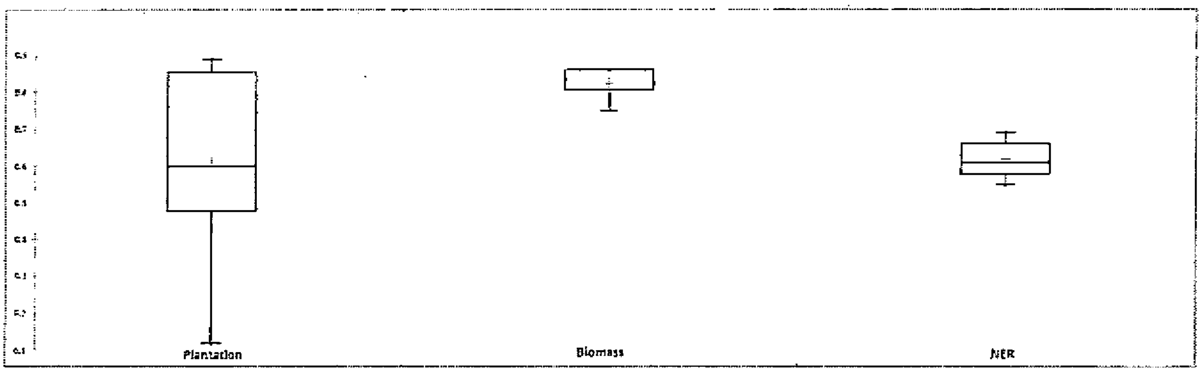



Fig. 10. Simpson diversity indices for regenerations of Eastern Attappady

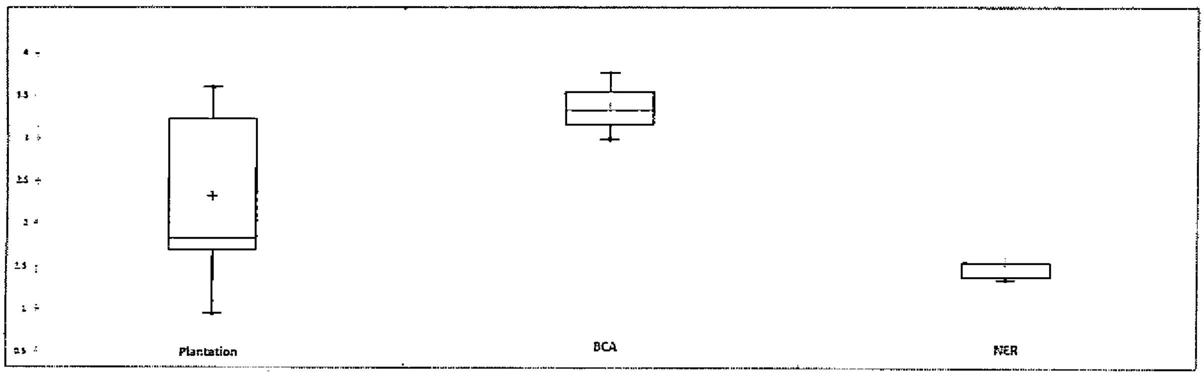



Fig. 11. Shannon-Weiner indices for regenerations of Eastern Attappady

Table 17. Location wise floristic diversity of regeneration in Eastern Attappady

| Location | Simpsons Index | Cd | Shannon Weiner index | H max | Equitability (E) |
|---|---|---|---|---|---|
| **Plantations** | | | | | |
| Agali | 0.51 | 0.49 | 1.83 | 4.00 | 0.46 |
| Melechavadiyoor | 0.89 | 0.11 | 3.60 | 4.46 | 0.81 |
| Palliyara | 0.12 | 0.78 | 0.95 | 4.17 | 0.23 |
| Pattimalam | 0.85 | 0.15 | 3.21 | 4.09 | 0.79 |
| Sambarcode | 0.45 | 0.55 | 1.67 | 4.09 | 0.41 |
| Vellamari | 0.86 | 0.14 | 3.25 | 4.09 | 0.80 |
| Kottathara | 0.60 | 0.40 | 1.72 | 3.32 | 0.52 |
| **Biomass Conservation Area** | | | | | |
| Palliyara | 0.86 | 0.14 | 3.77 | 5.17 | 0.73 |
| Sambarcode | 0.75 | 0.25 | 2.99 | 4.52 | 0.66 |
| Kottathara | 0.86 | 0.14 | 3.33 | 4.09 | 0.81 |
| **Non Eco-restored Area** | | | | | |
| Vellamari | 0.66 | 0.34 | 1.56 | 1.58 | 0.99 |
| Kottathara | 0.58 | 0.42 | 1.55 | 2.00 | 0.77 |
| Melechavadiyoor | 0.61 | 0.39 | 1.38 | 1.58 | 0.87 |
| Palliyara | 0.55 | 0.45 | 1.35 | 1.58 | 0.85 |
| Pattimalam | 0.69 | 0.31 | 1.93 | 2.32 | 0.83 |

### 4.3. Soil seed bank studies

#### 4.3.1. Species composition and seed density in the study area

Results of the seed bank studies on species composition and seed bank characteristics are given in Table 18. A total of 974 seedlings germinated from the soil seed bank. In total, six tree species were represented in soil seed bank (Plate 4). Majority of seeds in soil seed bank belonged to herbs and shrubs. Few climbers and grasses were also seen. No seedling were germinated in the control tray.

In Sambarcode plantation, 210 seedlings germinated belonging to ten plant species. Out of the ten species observed, seedlings of only three species viz., *Leucaena leucocephala, Albizia odoratissima* and *Senna siamea* were trees. Absolute density for *Leucaena leucocephala* (326.67 seeds/m$^2$), whose relative density and relative frequency were 71.17 and 20.83 respectively. *Albizia odoratissima* and *Senna siamea* had absolute density of 31.11 and 6.67 respectively. *Lantana camara* and grass species were represented in the seed bank. Absolute density, relative density and relative frequency were least for species *Chromalaena odartum* and *Vernonia cinerea.*

In Palliyara, only a single tree species *Leucaena leucocephala* was present in the seed bank. Herbs and shrubs dominated in the soil seed bank of Palliyara plantations. *Leucaena leucocephala* had highest absolute density (140 seeds/m$^2$), relative density and relative frequency 56.76 and 27.78 respectively. *Lantana camara* recorded absolute density of 20 seeds/m$^2$.

In Melechavadiyoor plantation, tree seedlings were totally absent in seed bank. Herbs and shrubs were dominated in the seed bank. Highest absolute density was recorded for *Vernonia cinerea* (73.33 seeds/m$^2$) followed by *Lantana camara* (26.67seeds/m$^2$).

In Vellamari plantation, out of two species, single tree species was represented in seed bank. *Leucaena leucocephala* had absolute density 73.33 seeds/ $m^2$. *Lantana camara* observed absolute density of 4.44 seeds/$m^2$.

Agali plantation soil seed bank consists of ten species in which three were tree species *Leucaena leucocephala, Samanea saman* and *Erythroxylum monogynum*. Herbs such as *Lantana camara, Chromalaena odorata, Vernonia cinerea, Solanum americanum* and *Euphorbia heterophylla* were also present (Table 18). *Leucaena leuocephala* had absolute density of 55.28 seeds/$m^2$, while, *Samanea saman* and *Erythroxylum monogynum* shared absolute density of 2.22 seeds/$m^2$. *Lantana camara* recorded highest absolute density of 117.78 seeds/$m^2$.

Seed bank regeneration accounted to 171 seedlings in Sambarcode BCA, belonging to 13 species in which three were tree species such as *Leucaena leucocephala, Albizia odoratissima* and *Senna siamea* having absolute densities of 246, 48.89 and 2.22 respectively (Table 19). The highest relative frequency and relative density were recorded in *Leucaena leucocephala* 18.12 and 63.16. Herbs and shrubs were dominated in the soil seed bank.

Seed bank study revealed that Palliyara BCA consists of 17 species and 113 seedlings. Herbs and shrubs dominated the seed bank of Palliyara. Among tree seedlings, *Leucaena leucocephala* recorded the highest absolute density of 22.12 followed by *Santalum album* (31.33). Only two tree species were recorded from the area. Relative density and relative frequency were highest for *Santalum album* 12.39 and 9.09. *Asystasia sps* recorded highest absolute density of 104.44.

In Kottathara BCA, 50 seedlings germinated from soil seed bank which belong to seven species. In that only two tree seed species were present. *Leucaena leucocephala* and *Senna siamea* had absolute density of 40.00 and 6.67 respectively. The relative density and relative frequency of *Leucaena*

*Albizia odaritissima*

*Erythroxylum monogynum*

*Samanea saman*

*Senna siamea*

*Leucaena leucocephala*

*Santalum album*

Plate 4. Major tree species germinated in soil seed bank

In Vellamari plantation, out of two species, single tree species was represented in seed bank. *Leucaena leucocephala* had absolute density 73.33 seeds/ $m^2$. *Lantana camara* observed absolute density of 4.44 seeds/$m^2$.

Agali plantation soil seed bank consists of ten species in which three were tree species *Leucaena leucocephala, Samanea saman* and *Erythroxylum monogynum*. Herbs such as *Lantana camara, Chromalaena odorata, Vernonia cinerea, Solanum americanum* and *Euphorbia heterophylla* were also present (Table 18). *Leucaena leuocephala* had absolute density of 55.28 seeds/$m^2$, while, *Samanea saman* and *Erythroxylum monogynum* shared absolute density of 2.22 seeds/$m^2$. *Lantana camara* recorded highest absolute density of 117.78 seeds/$m^2$.

Seed bank regeneration accounted to 171 seedlings in Sambarcode BCA, belonging to 13 species in which three were tree species such as *Leucaena leucocephala, Albizia odoratissima* and *Senna siamea* having absolute densities of 246, 48.89 and 2.22 respectively (Table 19). The highest relative frequency and relative density were recorded in *Leucaena leucocephala* 18.12 and 63.16. Herbs and shrubs were dominated in the soil seed bank.

Seed bank study revealed that Palliyara BCA consists of 17 species and 113 seedlings. Herbs and shrubs dominated the seed bank of Palliyara. Among tree seedlings, *Leucaena leucocephala* recorded the highest absolute density of 22.12 followed by *Santalum album* (31.33). Only two tree species were recorded from the area. Relative density and relative frequency were highest for *Santalum album* 12.39 and 9.09. *Asystasia sps* recorded highest absolute density of 104.44.

In Kottathara BCA, 50 seedlings germinated from soil seed bank which belong to seven species. In that only two tree seed species were present. *Leucaena leucocephala* and *Senna siamea* had absolute density of 40.00 and 6.67 respectively. The relative density and relative frequency of *Leucaena* *leucocephala* and *Senna siamea* were 36 and 33 and 6, 6.6. *Solanum americanum, Ageratum conyzoides, Lantana camara,* and *Blumea virens* were also present.

Soil seed bank study in non ecorestored area showed that in Pattimalam and Kottathara regions only grasses were present (Table 20). In Melechavadiyoor, seed bank regeneration was absent. In Palliyara and Vellamari region absolute density recorded for *Santalum album* and *Leucaena leucocephala* were 55.56 and 2.22 respectively.

Table 18. Species composition and seed density of soil seed bank in plantations

| Sl No | Species | Absolute Density (seeds /m$^2$) | Relative Density | Relative Frequency | Habit |
|---|---|---|---|---|---|
| **Sambarcode** | | | | | |
| 1 | *Leucaena leucocephala* | 326.67 | 71.71 | 20.83 | Tree |
| 2 | *Grass* | 44.44 | 9.76 | 20.83 | Grass |
| 3 | *Albizia odoratissima* | 31.11 | 6.83 | 16.67 | Tree |
| 4 | *Sida cordata* | 4.44 | 0.98 | 4.17 | Herb |
| 5 | *Lantana camara* | 24.44 | 5.37 | 12.50 | Shrub |
| 6 | *Abrus precatorius* | 4.44 | 0.98 | 4.17 | Climber |
| 7 | *Chromolaena odarata* | 2.22 | 0.49 | 4.17 | Shrub |
| 8 | *Ageratum conyzoides* | 8.89 | 1.95 | 8.33 | Herb |
| 9 | *Senna siamea* | 6.67 | 1.46 | 4.17 | Tree |
| 10 | *Vernonia cinerea* | 2.22 | 0.49 | 4.17 | Shrub |
| | | 455.56 | | | |
| **Palliyara** | | | | | |
| 1 | *Unknown A* | 53.33 | 21.62 | 22.22 | Herb |
| 2 | *Grass* | 22.22 | 9.01 | 16.67 | Grass |

| Sl No | Species | Absolute Density (seeds /m²) | Relative Density | Relative Frequency | Habit |
|---|---|---|---|---|---|
| 3 | *Leucaena leucocephala* | 140.00 | 56.76 | 27.78 | Tree |
| 4 | *Hedyotis auriculata* | 2.22 | 0.90 | 5.56 | Shrub |
| 5 | *Lantana camara* | 20.00 | 8.11 | 11.11 | Shrub |
| 6 | *Sauropus quadrangularis* | 6.67 | 2.70 | 11.11 | Shrub |
| 7 | *Ageratum conyzoides* | 2.22 | 0.90 | 5.56 | Herb |
| | | 246.67 | | | |
| **Melechavadiyoor** | | | | | |
| 1 | *Vernonia cinerea* | 73.33 | 70.22 | 62.5 | Shrub |
| 2 | *Lantana camara* | 26.67 | 25.53 | 12.5 | Shrub |
| 3 | *Grass* | 2.22 | 2.13 | 12.5 | Grass |
| 4 | *Chromalaena odorata* | 2.22 | 2.13 | 12.5 | Shrub |
| | | 104.44 | | | |
| **Vellamari** | | | | | |
| 1 | *Leucaena leucocephala* | 73.33 | 94.28 | 66.67 | Tree |
| 2 | *Lantana camara* | 4.44 | 5.71 | 33.33 | Shrub |
| | | 77.78 | | | |
| **Agali** | | | | | |
| 1 | *Leucaena leucocephala* | 55.56 | 19.69 | 21.05 | Tree |
| 2 | *Samanea saman* | 2.22 | 0.79 | 5.26 | Tree |
| 3 | *Lantana camara* | 117.78 | 41.73 | 21.05 | Shrub |
| 4 | *Chromolaena odorata* | 20.00 | 7.09 | 5.26 | Shrub |
| 5 | *Grass* | 37.78 | 13.39 | 10.53 | Grass |
| 6 | *Erythroxylum monogynum* | 2.22 | 0.79 | 5.26 | Tree |
| 7 | *Vernonia cinerea* | 17.78 | 6.30 | 10.53 | Herb |
| 8 | *Solanum americanum* | 6.67 | 2.36 | 5.26 | Herb |
| 9 | *Tinospora cordifolia* | 2.22 | 0.79 | 5.26 | Climber |
| 10 | *Unknown A* | 2.22 | 0.79 | 5.26 | Herb |
| 11 | *Euphorbia heterophylla* | 17.78 | 6.30 | 5.26 | Herb |
| | | 282.22 | | | |
| **Pattimalam** | | | | | |
| 1 | *Leucaena leucocephala* | 73.33 | 75.00 | 45.45 | Tree |
| 2 | *Grass* | 2.22 | 2.27 | 9.09 | Grass |

| Sl No | Species | Absolute Density (seeds /m$^2$) | Relative Density | Relative Frequency | Habit |
|---|---|---|---|---|---|
| 3 | *Phyllanthus amarus* | 2.22 | 2.27 | 9.09 | Herb |
| 4 | *Tinospora cordifolia* | 2.22 | 2.27 | 9.09 | Climber |
| 5 | *Centrosema pubescens* | 2.22 | 2.27 | 9.09 | Climber |
| 6 | *Albizia odoratissima* | 2.22 | 2.27 | 9.09 | Tree |
| 7 | *Unknown A* | 13.33 | 13.64 | 9.09 | Herb |
| | | 97.78 | | | |
| **Kottathara** | | | | | |
| 1 | *Leucaena leucocephala* | 15.56 | 30.44 | 40 | Tree |
| 2 | *Unknown A* | 6.67 | 13.04 | 10 | Grass |
| 3 | *Grass* | 4.44 | 8.70 | 20 | Grass |
| 4 | *Vernonia cinerea* | 2.22 | 4.35 | 10 | Shrub |
| 5 | *Tinospora cordifolia* | 4.44 | 8.70 | 10 | Climber |
| 6 | *Senna siamea* | 17.78 | 34.78 | 10 | Tree |
| | | 51.11 | | | |

Table 19. Species composition and seed density of soil seed bank in biomass conservation area

| Sl No | Species | Absolute Density (seeds /m$^2$) | Relative Density | Relative Frequency | Habit |
|---|---|---|---|---|---|
| | | **Sambarcode BCA** | | | |
| 1 | *Grass* | 15.56 | 4.09 | 11.11 | Grass |
| 2 | *Leucaena leucocephala* | 240.00 | 63.16 | 18.52 | Tree |
| 3 | *Albizia odoratissima* | 48.89 | 12.87 | 11.11 | Tree |
| 4 | *Vernonia cinerea* | 4.44 | 1.17 | 3.70 | Shrub |
| 5 | *Lantana camara* | 28.89 | 7.60 | 14.81 | Shrub |
| 6 | *Unknown A* | 2.22 | 0.58 | 3.70 | Herb |
| 7 | *Ageratum conyzoides* | 11.11 | 2.92 | 7.41 | Herb |
| 8 | *Chromalaena odorata* | 8.89 | 2.34 | 7.41 | Shrub |
| 9 | *Oxalis corniculata* | 2.22 | 0.58 | 3.70 | Herbs |
| 10 | *Sida cordata* | 11.11 | 2.92 | 7.41 | Herb |
| 11 | *Ipomoea marginata* | 2.22 | 0.58 | 3.70 | Climber |
| 12 | *Senna siamea* | 2.22 | 0.58 | 3.70 | Tree |
| 13 | *Solanum americanum* | 2.22 | 0.58 | 3.70 | Herb |
| | | 380.00 | | | |
| | | **Palliyara BCA** | | | |
| 1 | *Mikania micrantha* | 2.22 | 0.88 | 4.55 | Climber |
| 2 | *Leucaena leucocephala* | 22.22 | 8.85 | 4.55 | Tree |
| 3 | *Bidens sulphura* | 4.44 | 1.77 | 4.55 | Herb |
| 4 | *Ageratum conyzoides* | 6.67 | 2.65 | 4.55 | Herb |
| 5 | *Vernonia cinerea* | 4.44 | 1.77 | 4.55 | Shrub |
| 6 | *Euphorbia heterophylla* | 6.67 | 2.65 | 4.55 | Herb |
| 7 | *Grass* | 6.67 | 2.65 | 9.09 | Grass |
| 8 | *Oxalis corniculata* | 13.33 | 5.31 | 9.09 | Herb |
| 9 | *Unknown A* | 4.44 | 1.77 | 4.55 | Herb |
| 10 | *Lantana camara* | 8.89 | 3.54 | 4.55 | Shrub |

| Sl No | Species | Absolute Density (seeds /m²) | Relative Density | Relative Frequency | Habit |
|---|---|---|---|---|---|
| 11 | *Asystasia sps.* | 104.44 | 41.59 | 13.64 | Shrub |
| 12 | *Solanum americanum* | 8.89 | 3.54 | 4.55 | Herb |
| 13 | *Sauropus quadrangularis* | 8.89 | 3.54 | 4.55 | Herb |
| 14 | *Santalum album* | 31.11 | 12.39 | 9.09 | Tree |
| 15 | *Tinospora cordifolia* | 2.22 | 0.88 | 4.55 | Climber |
| 16 | *Sida cordata* | 2.22 | 0.88 | 4.55 | Shrub |
| 17 | *Pseudarthria viscida* | 13.33 | 5.31 | 4.55 | Herb |
| | | 251.11 | | | |
| **Kottathara BCA** | | | | | |
| 1 | *Leucaena leucocephala* | 40.00 | 36.00 | 33.33 | Tree |
| 2 | *Solanum americanum* | 6.67 | 6.00 | 6.67 | Herb |
| 3 | *Ageratum conyzoides* | 20.00 | 18.00 | 20.00 | Herb |
| 4 | *Lantana camara* | 17.78 | 16.00 | 13.33 | Shrub |
| 5 | *Blumea virens* | 17.78 | 16.00 | 13.33 | Herb |
| 6 | *Senna siamea* | 6.67 | 6.00 | 6.67 | Tree |
| 7 | *Tinospora cordifolia* | 2.22 | 2.00 | 6.67 | Climber |
| | | 111.11 | | | |

Table 20. Species composition and seed density of soil seed bank in non eco-restored area

| Location | Simpsons Index | Cd | Shannon Weiner index | H max | Equitability (E) |
|---|---|---|---|---|---|
| Palliyara NER | | | | | |
| 1 | *Lantana camara* | 6.67 | 10.00 | 33.33 | Shrub |
| 2 | *Grass* | 4.44 | 6.67 | 33.33 | Grass |
| 3 | *Santalum album* | 55.56 | 83.33 | 33.33 | Tree |
| | | 66.67 | | | |
| Kottathara NER | | | | | |
| 1 | *Grass* | 17.78 | 100.00 | 100 | Grass |
| | | 17.78 | | | |
| Vellamari NER | | | | | |
| 1 | *NIL* | 0.00 | Nil | Nil | |
| | | | | | |
| Melechavadiyoor NER | | | | | |
| 1 | *Grass* | 8.89 | 57.13 | 50 | Grass |
| 2 | *Leucaena leucocephala* | 2.22 | 14.28 | 25 | Tree |
| 3 | *Lantana camara* | 4.44 | 28.56 | 25 | Shrub |
| | | 15.56 | | | |
| Pattimalam NER | | | | | |
| 1 | *Grass* | 6.67 | 100 | 100 | Grass |

### 4.3.2. Season wise germination in soil seed bank

In Table 21, season-wise germination of soil seed bank showed that maximum seeds were germinated in the month of March (440 seeds) followed by July (354 seeds) and least number of seeds germinated during the month of October (180 seeds). Maximum number of seedlings were germinated in Sambarcode plantation (205 seeds) followed by Sambarcode BCA (171 seeds). In Vellamari NER, species was absent in its soil seed bank.

Table 21. Season- wise soil seed bank germination in Eastern Attappady

| Location | March | July | October |
|---|---|---|---|
| Sambarcode | 135 | 40 | 30 |
| Palliyara | 62 | 29 | 20 |
| Melechavadiyoor | 1 | 41 | 6 |
| Vellamari | 2 | 32 | 1 |
| Agali | 32 | 69 | 25 |
| Pattimalam | 27 | 13 | 4 |
| Kottathara | 8 | 12 | 3 |
| Sambarcode BCA | 124 | 13 | 34 |
| Palliyara BCA | 27 | 51 | 35 |
| Kottathara BCA | 11 | 28 | 11 |
| Palliyara NER | 5 | 16 | 9 |
| Kottathara NER | 2 | 4 | 2 |
| Vellamari NER | 0 | 0 | 0 |
| Melechavadiyoor NER | 2 | 5 | 0 |
| Pattimalam NER | 2 | 1 | 0 |
| | 440 | 354 | 180 |

An attempt was made to do a hierarchical cluster analysis of the plantation, BCA and non ecorestored area based on species composition and density of soil seed bank. The analysis used Chi-square measure for classification. The Dendrogram of the classification is given in Figure 12. Two clusters were formed at the cluster distance of 25 units. Melechavadiyoor plantations, Palliyara non ecorestored area and Palliyara BCA formed a single cluster. While the rest formed the other cluster. At a cluster distance of 10 Sambarcode plantations, Sambarcode BCA and Kottathara BCA separated out of the cluster. While Kottathara, Palliyara, Vellamari, Pattimalam plantations and Melechavadiyoor non ecorestored area clustered together at a cluster distance of 5 units. Agali and Sambarcode plantation separately formed clusters at this distance.

PCA bi-plot analysis showed that Agali plantations was distant from the origin and was the only one in its quadrat. It had the highest species diversity in the soil seed bank, comprising of *Erythroxylum monogynum* and *Samanea saman* (Fig. 13). Sambarcode plantation and BCA was found in the top right quadrat. Sambarcode plantations and BCA had lowest species diversity of seeds in the soil seed bank, but the abundance of these seeds were high in the seed bank. *Leucaena leucocephala* and *Senna siamea* were recorded from this quadrat. All the NER along with the plantations except Palliyara were clustered together in the bottom left quadrat.

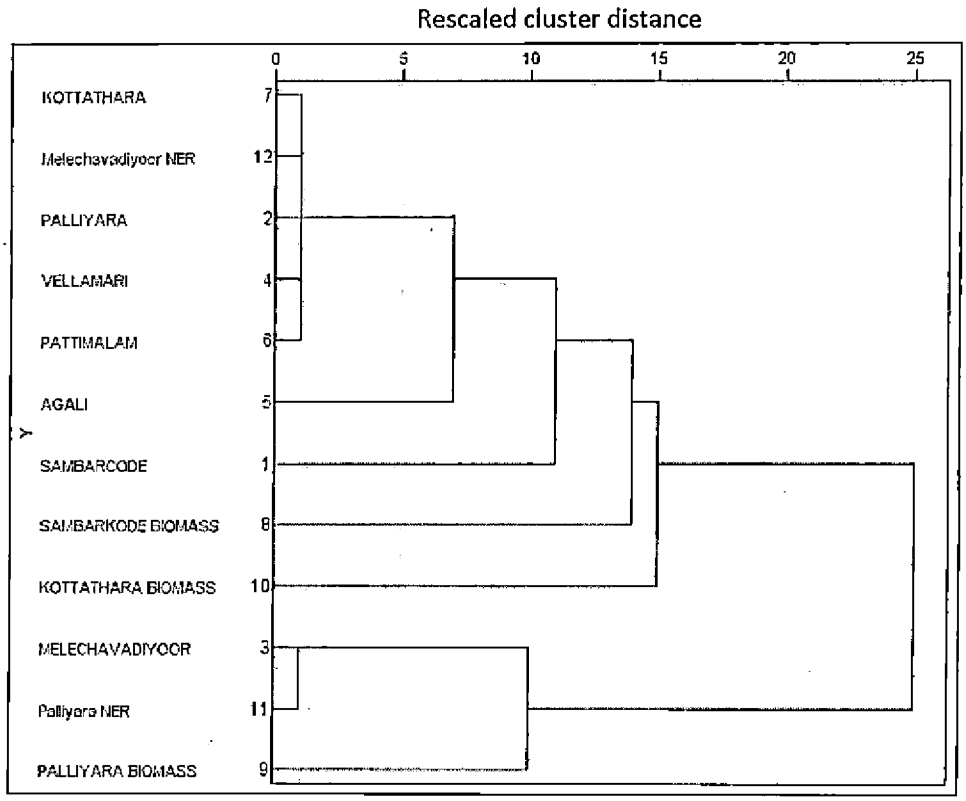



Fig. 12. Dendrogram of Soil seed bank

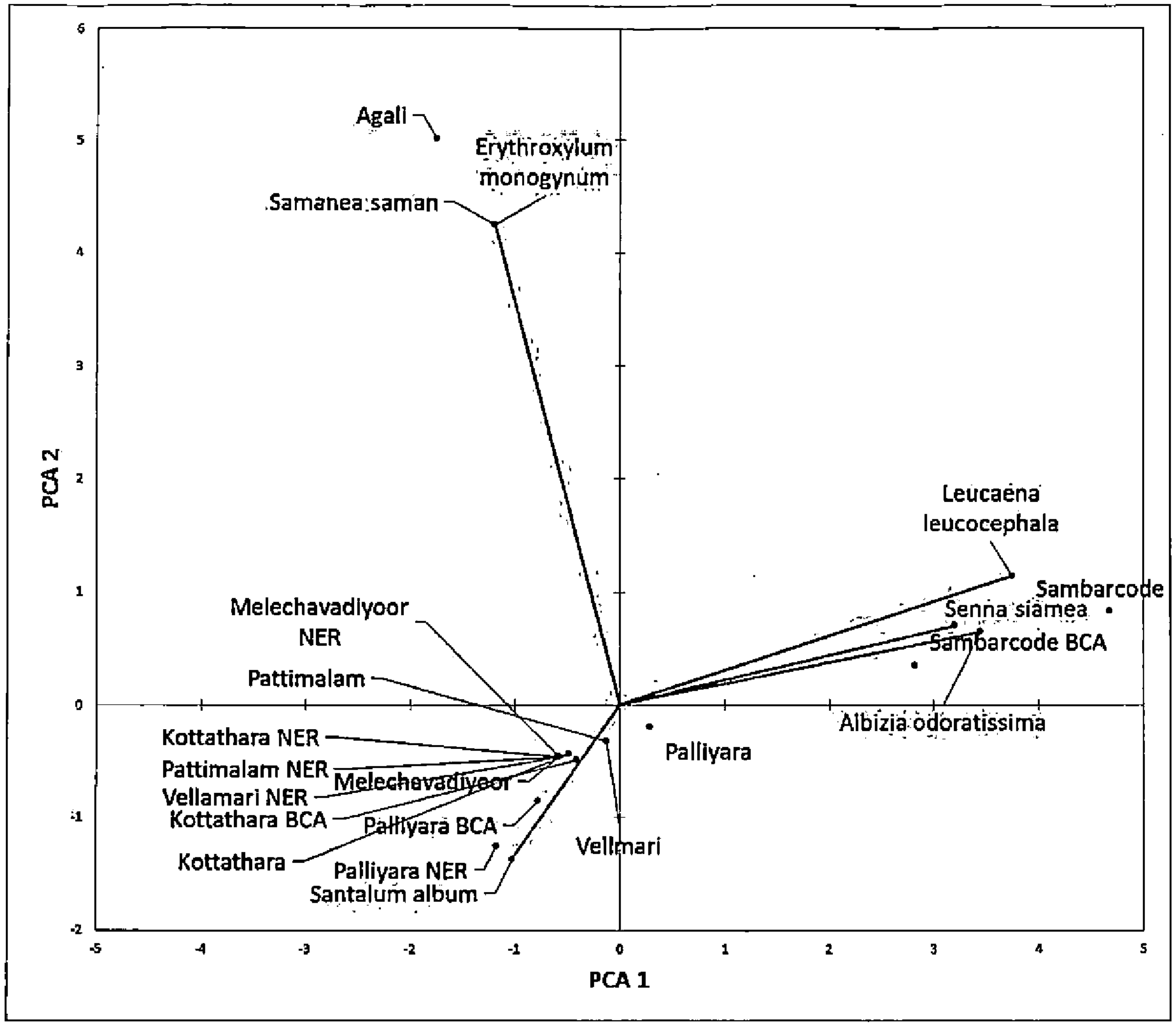



Fig. 13.PCA bi-plot of East Attappady soil seed bank with respect to species

### 4.3.3. Species diversity of soil seed bank in Eastern Attappady

Based on the germinated seedlings, species diversity of soil seed bank was assessed (Table 20). The Simpsons index was recorded highest in Sambarcode 0.81 followed by Agali 0.46 and Pattimalam 0.06. In Palliyara, Vellamari and Kottathara concentration of dominance observed the maximum value of one. Agali and Sambarcode shared equal value for Shannon Weiner index 0.55, Hmax 1.58 and equitability 0.35. In Melechavadiyoor plantation tree species representation was absent. Palliyara, Vellamari and Kottathara consist of single species.

In BCA area, highest Simpsons index was recorded for Palliyara 0.49 followed by Sambarcode (0.29) and Kottathara (0.24). Shannon Weiner index followed similar trend Palliyara 0.98, for Sambarcode 0.72 and for Kottathara 0.59. Hmax (1.58) was highest for Sambarcode and highest equitability for Palliyara 0.98.

In non ecorestored area, Melechavadiyoor and Palliyara had highest concentration of dominance value one. For region such as Vellamari, Kottathara and Pattimalam tree germination was absent.

Box plot analysis of Simpson's diversity indices was highest in plantations and nil for non-eco-restored areas in the soil seed bank (Fig. 14). Variation in plantation was highest and the least in the NER's. While for Shannon-Weiner diversity indices, it was highest for the biomass conservation area followed by plantations (Fig. 15). Variation in plantation was highest and the least in the NER's

Table 22. Location wise soil seed bank diversity in Eastern Attappady

| Location | Simpsons Index | Cd | Shannon Weiner index | H max | Equitability (E) |
|---|---|---|---|---|---|
| **Plantations** | | | | | |
| Agali | 0.46 | 0.54 | 0.55 | 1.58 | 0.35 |
| Melechavadiyoor | Nil | Nil | Nil | Nil | Nil |
| Palliyara | 0 | 1 | 0 | 0 | 0 |
| Pattimalam | 0.06 | 0.94 | 0.19 | 1.00 | 0.19 |
| Sambarcode | 0.81 | 0.19 | 0.55 | 1.58 | 0.35 |
| Vellamari | 0 | 1 | 0 | 0 | 0 |
| Kottathara | 0 | 1 | 0 | 0 | 0 |
| **Biomass Conservation Area** | | | | | |
| Palliyara | 0.49 | 0.51 | 0.98 | 1.00 | 0.98 |
| Sambarcode | 0.29 | 0.71 | 0.72 | 1.58 | 0.45 |
| Kottathara | 0.24 | 0.76 | 0.59 | 1.00 | 0.59 |
| **Non Eco-restored Area** | | | | | |
| Vellamari | Nil | Nil | Nil | Nil | Nil |
| Kottathara | Nil | Nil | Nil | Nil | Nil |
| Melechavadiyoor | 0 | 1 | 0 | 0 | 0 |
| Palliyara | 0 | 1 | 0 | 0 | 0 |
| Pattimalam | Nil | Nil | Nil | Nil | Nil |

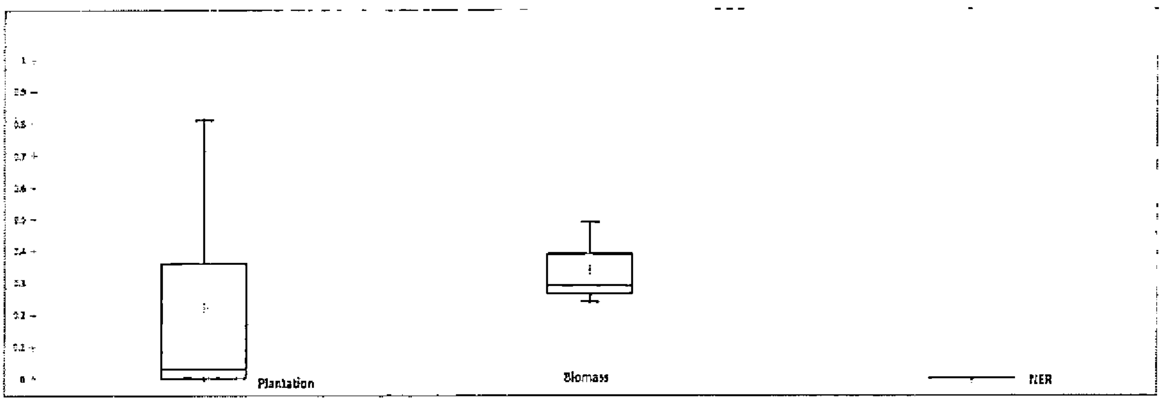



Fig. 14. Simpson diversity indices for soil seed bank in Eastern Attappady

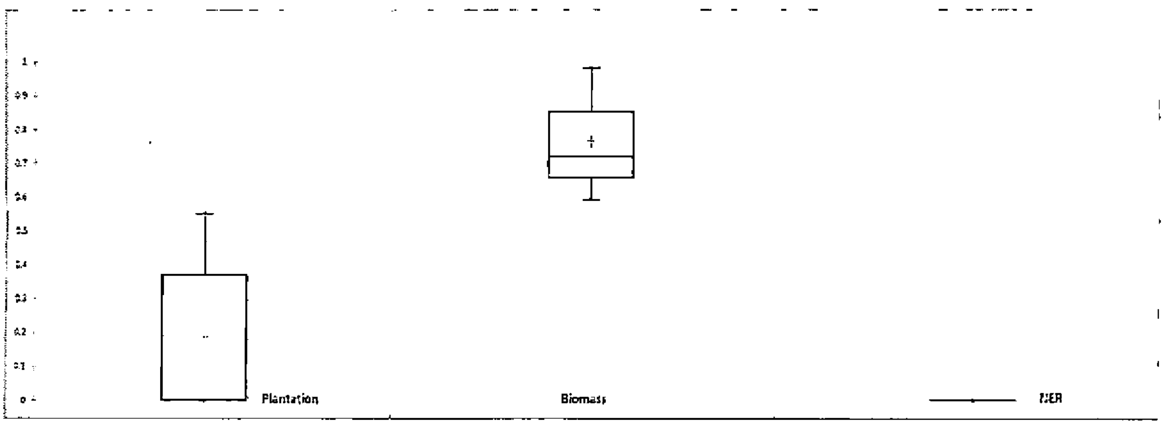



Fig. 15. Shannon-Weiner Index for soil seed bank in Eastern Attappady

### 4.5. Sorensen's similarity index

#### 4.5.1. Similarity index for plantation area

Sorensen similarity index between aboveground vegetation and seed bank of plantation (Table 21) revealed that highest similarity was observed in Pattimalam plantation 0.14 followed by Kottathara plantation 0.13. In Melechavadiyoor species were absent, similarity index of Sambarcode, Vellamari, Palliyara and Agali were 0.12, 0.08, 0.06 and 0.05 respectively. Sorensen similarity index between seed bank and regeneration revealed that highest similarity was observed in Sambarcode plantation 0.21 followed by Vellamari plantation 0.15. In Melechavadiyoor and Kottathara tree species were absent. Similarity index of Pattimalam, Vellamari, Palliyara and Agali were 0.12, 0.15, 0.11 and 0.11 respectively. Sorensen similarity index between aboveground vegetation and regeneration revealed that highest similarity was observed in Kottathara plantation 0.74 followed by Melechavadiyoor and Pattimalam 0.68. Vellamari plantation recorded 0.63. Similarity index of Agali and Palliyara were 0.58 and 0.57. Sambarcode plantation recorded the least 0.43.

#### 4.5.2. Similarity index for BCA area

In BCA area, higher similarity index was observed in Sambarcode BCA 0.09 followed by Kottathara and Palliyara 0.08. In BCA area higher similarity index was observed in Kottathara BCA 0.11 followed by Sambarcode 0.07 and Palliyara 0.05. In BCA area higher similarity index was observed in Kottathara BCA 0.79 followed by Palliyara 0.74 and Sambarcode 0.59.

#### 4.5.3. Similarity index for non ecorestored area

In Non ecorestored areas Palliyara region only recorded 0.05. In non ecorestored areas higher similarity index was observed in Melechavadiyoor region 0.86 followed by Vellamari 0.75 and Kottathara 0.44. Pattimalam and Palliyara region recorded 0.25 and 0.22.

Table 23. Sorensen similarity index worked out in Eastern Attappady area

| Sl No | Location | Similarity Index ABVG & SSB | Similarity Index SSB & REGN | Si Index ABVG & REGN |
|---|---|---|---|---|
| **Plantation** | | | | |
| 1. | Agali | 0.05 | 0.11 | 0.58 |
| 2. | Melechavadiyoor | 0 | 0 | 0.68 |
| 3. | Palliyara | 0.06 | 0.11 | 0.57 |
| 4. | Pattimalam | 0.14 | 0.12 | 0.68 |
| 5. | Sambarcode | 0.12 | 0.21 | 0.43 |
| 6. | Vellamari | 0.08 | 0.15 | 0.63 |
| 7. | Kottathara | 0.13 | 0 | 0.74 |
| **Biomass Conservation Area** | | | | |
| 1. | Palliyara | 0.08 | 0.05 | 0.74 |
| 2. | Sambarcode | 0.09 | 0.07 | 0.59 |
| 3. | Kottathara | 0.08 | 0.11 | 0.79 |
| **Non Ecorestored Area** | | | | |
| 1. | Vellamari | 0 | 0 | 0.75 |
| 2. | Kottathara | 0 | 0 | 0.44 |
| 3. | Melechavadiyoor | 0 | 0 | 0.86 |
| 4. | Palliyara | 0 | 0.50 | 0.22 |
| 5. | Pattimalam | 0 | 0 | 0.25 |

ABVG- Aboveground vegetation, SSB- Soil seed bank, REGN- Regeneration

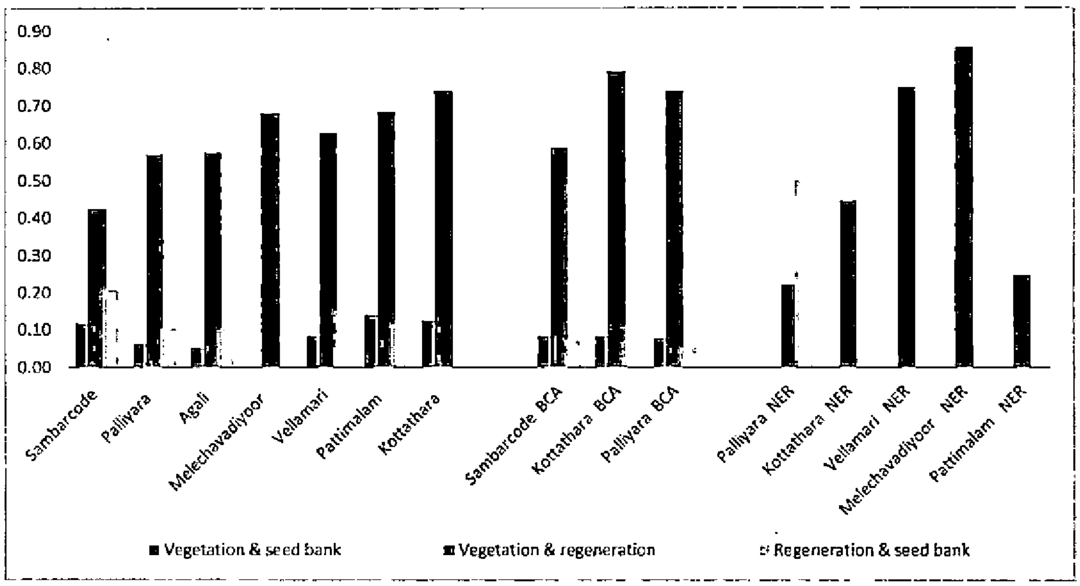



Fig. 16. Sorensen Similarity Index in Eastern Attappady area

# Discussion

# 5. DISCUSSION

The present study was done to investigate the impact of eco-restoration on soil seed bank of Eastern Attappady and relate it to the vegetation available in the area. The results of the study are discussed in this chapter.

## 5.1 Vegetation studies

### 5.1.1. Species composition and vegetation structure

The climatic regime of Attappady has been classified into four regimes based on rainfall and duration of dry seasons by KFRI (1991). Attappady mostly receives high rainfall, so the areas receiving high rainfall were designated as the first regime (Table 24) (Appendix I). They are located on the western and southern sectors and receive bulk of the precipitation (70%) during the south-west monsoon (June - September). The northern and the southern part of this zone are forested while the central portion in this zone has undergone severe land-use changes from forest to agro-forest, agriculture and monoculture cash crop plantations. The biotope of the first regime is evergreen forests. The second rainfall regime (<6 month dry season, 1000-2000 mm rainfall) is found close to the heavy rain fall area but towards south east. The third regime lies in the northern portion of the same tract, although receiving the same amount of rain fall, but has a dry season lasting more than six months in a year. The biotope changes from drier tracts of moist deciduous forests to dry deciduous forests. The fourth rainfall regime falls in the eastern sector of Attappady, which is the low rainfall zone (<1000 mm). This area receives bulk of rainfall mainly from the north-east monsoon. The biotope of this regime is dry deciduous forest with frequent individual trees of the moist deciduous type. The rainfall regimes under which the current study is conducted (Eastern Attappady) falls in the third and fourth regimes. The locations Agali, Palliyara and Sambarcode were characterised by receiving the rainfall amount of 1000 mm to 2000 mm and period of dry season less than 6 months in a year, while areas like Kottathara, Melechavadiyoor and Vellamari falls under areas where dry seasons lasts more than nine months.

Table 24. Different rainfall regime in Attappady area (KFRI, 1991)

| Rainfall regime | Rainfall | Area | Location |
|---|---|---|---|
| 1st regime | High rainfall- >2000 mm | 334 $km^2$ | Western and southern Attappady |
| 2nd regime | Medium rainfall- 1000-2000mm (< 6month dry season) | 65 $km^2$ | South-East Attappady |
| 3rd regime | Medium rainfall- 1000-2000mm (>6 month dry season) | 154 $km^2$ | North-East Attappady |
| 4th regime | Low rainfall- <1000mm | 178 $km^2$ | Eastern Attappady |

Cluster analysis of above ground vegetation in the study area revealed that Palliyara biomass, Sambarcode biomass and Agali plantation were found to be the most distant cluster from the rest of the study area. These areas fall in the wetter tracts of Attappady and hence can be attributed to the rainfall pattern present in this region.

The cluster analysis revealed that non eco-restored areas are clustered together (Fig. 2). This clearly indicated that vegetation structure and composition of this area were very poor compared to plantations and biomass areas. It was also found that Pattimalam, Kottathara and Vellamari were proximal to NER clusters which indicate that the eco-restoration is poorly performing in these areas. These plantations too fall in the drier tracts of Attappady. The reason for this poor performance can be that the process of eco-restoration is gradual in drier tracts (Murphy and Lugo, 1986). It may be explained that even though both forests grow similarly in the wet season, dry forests decrease in growth or even stop growing during the dry season.

The study revealed that significant differences were found among plantations with respect to species composition and vegetation structure (Table 25). *Leucaena leucocephala* with higher IVI values dominated plantation of wetter regions of Agali (66.41), Palliyara (112.32) and Sambarcode (75.79). While in Vellamari, Melechavadiyoor, Pattimalam and Kottathara plantation, *Albizia amara* was the dominant species. Study conducted by Vidyasagaran and Anilkumar (2009) in ecorestored plantations of Attappady also found that *Leucaena leucocephala* and *Albizia amara* were predominant because they were planted extensively and their survival rate was higher. The reason for their extensive growth and high survival rate is that they are pioneer species suitable for this ecosystem. Pioneer tree species are light demanding, effective in producing large number of seeds, dispersing seeds over long distance and successful in germination of large number of seeds and well developed capacities to germinate in different ground vegetation layers and other difficult circumstances including exposed mineral soils (Otto, 2000).

*Leucaena leucocephala* is a known aggressive colonizer of ruderal sites and disturbed vegetation in many places. This has been attributed to its precocious year-round flowering and fruiting, abundant seed production, self-fertility, hard seed coat, and ability to resprout after fire or cutting (Orwa *et al.*, 2009). In the present study, *Albizia amara* is an indigenous fast growing pioneer species. *Albizia amara* is a strong light-demander, intolerant of shade, very hardy and shows marked resistance to drought. It was observed that *Leucaena leucocephala* grows well only in sub humid or humid climates with moderate dry seasons of up to 6-7 months and cannot withstand prolonged drought while *Albizia amara* can withstand higher temperatures up to $47^0$C and low rainfall of 400 m (Orwa *et al.*, 2009). In the present study *Albizia amara* was found to be a dominant species in the drier tracts of Attappady like Melechavadiyoor, Pattimalam, Vellamari and Kottathara. Though *Leucaena leucocephala* were found in the drier tracts, the profuse growth of *Leucaena leucocephala* was in the wetter regions of Attappady such as Palliyara, Sambarcode and Agali.

The present study of biomass and plantation area showed significant differences in species composition and vegetation structure. It was observed that planted tree species like *Leucaena leucocephala, Albizia amara; Senna siamea, Mundulea sericea and Chloroxylon sweitenia* were dominating the plantation

(Figure 8 and 9). This can be explained as these species were selected based on suitability to this ecosystem.

For eco-restoration, forest area identified as having more than 40 percent crown cover was designated as Biomass Conservation Areas (BCA) and given protection from grazing, fire wood collection and forest fires. The assumption is that with sufficient protection, areas with such remnant vegetation will recover in due course. The remnant vegetation often plays a critical role in forest recovery, promoting rapid increases in species richness, tree density and aboveground biomass (Guariguata et al., 1995). Shrubs and trees in such areas attract seed dispersers (Chazdon, 2003) and hence recover without much interventions. Among BCA's studied, Kottathara BCA was significantly different to Palliyara and Sambarcode BCA's, which had a better vegetation structure (Table 26). Species composition and vegetation structure of Kottathara BCA were similar to plantations. Structural analysis of BCA revealed that presence of tree species such as *Albizia amara, Givotia moluccana, Azadirachta indica, Tectona grandis, Diospyros cordifolia, Chloroxylon swietenia* and *Anogeissus latifolia* in Palliyara BCA and Sambarcode BCA constitute moist deciduous forests type (Fig 18). Presence of moist deciduous trees in dry tracts may be due to the fact that these forests might have been moist deciduous previously and destroyed later (KFRI, 1991). The reason for the difference between the Kottathara BCA and the rest of the BCA's can be attributed to the lower moisture regimes. So it's assumed that the rainfall regime of the region is one of the main driving force for this vegetation structure. The main obstacles to ecological restoration of dry area are often water limitation. Water scarcity influences growth patterns; productivity and cycling of organic matter, and can additionally limit natural regeneration by affecting seed germination and seedling establishment (Lieberman and Li, 1992). Rate of ecological succession has been observed to be slow in dry area in terms of plant growth and aboveground biomass accumulation compared to humid areas. Thus restoration in the face of drought or limited access to water often can be a challenge.

The study also showed that species composition and vegetation structure of eco-restored area and non-eco-restored area were significantly different. This clearly showed that ecorestoration had positive impact on the study area. Further, the study also indicated that measures of vegetation structure changed rapidly due to planting and early establishment of pioneer species in the reforested site. Pioneer species are mostly used in restoration because main objective of restoration projects were protection of the natural resources rather than to improve the diversity in the region (Barbosa and Pizo, 2006). Plantations with pioneer species show fast vegetation establishment over degraded lands and possibly improved soil conservation. Pioneer species quickly accumulate biomass (Guariguata *et al.*, 1995) and provide a diverse vertical structure and canopy cover. Tree species, whether native, naturalized exotic or exotic, are capable of catalysing native forest succession on deforested, degraded site where natural regeneration processes in the absence of planted tree cover are seriously impeded by the absence of a viable soil seed bank, limitations on seed inputs by wildlife, grass competition, and unfavourable micro environmental conditions (Parrotta et al., 1997).

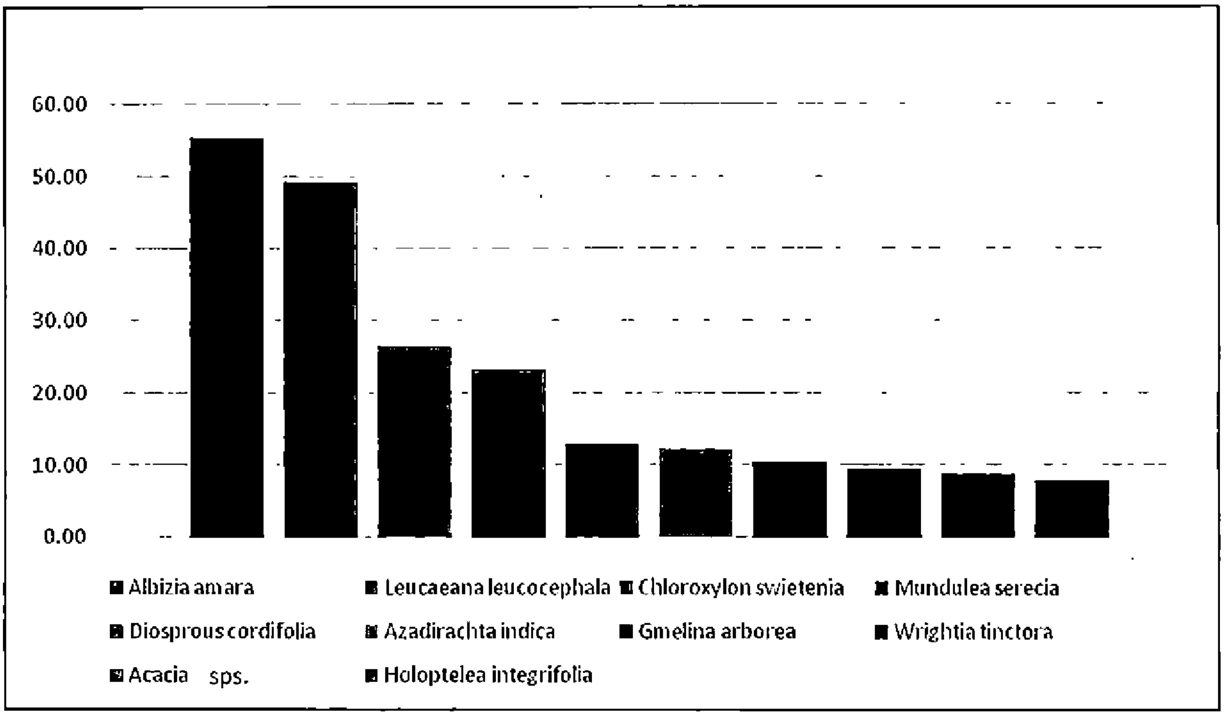



Fig. 17. Important value index (IVI) of major tree species in the plantation area

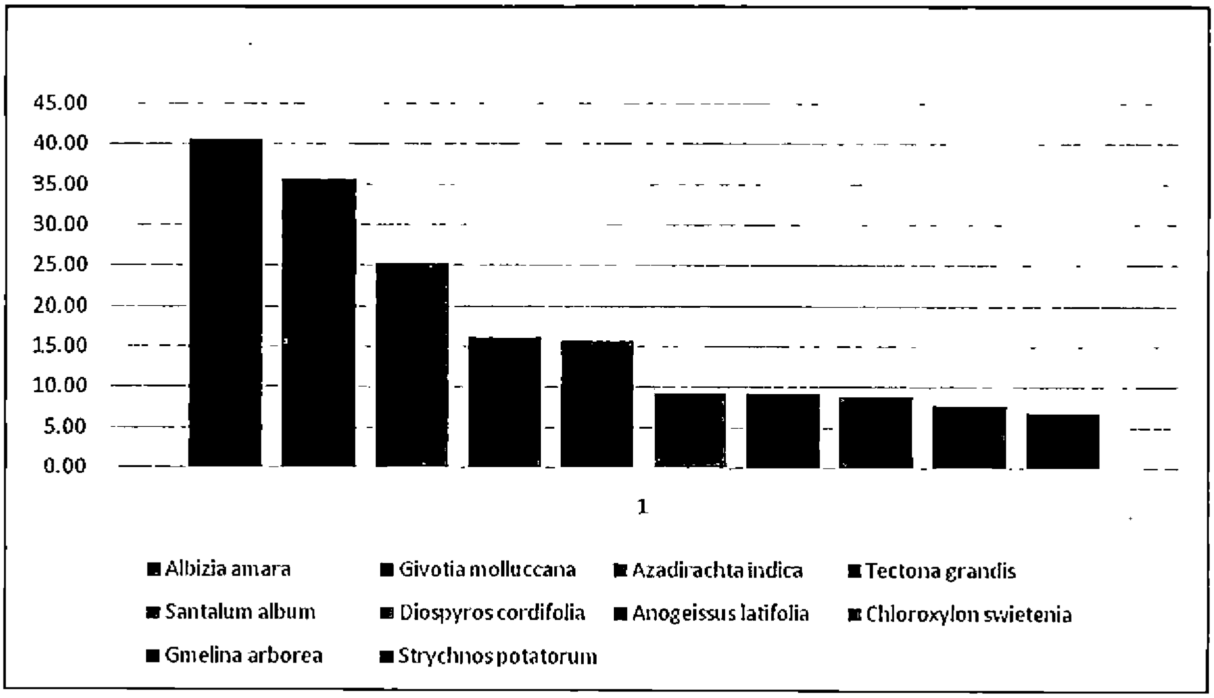



Fig. 18. Important value index (IVI) of major tree species in the biomass conservation area

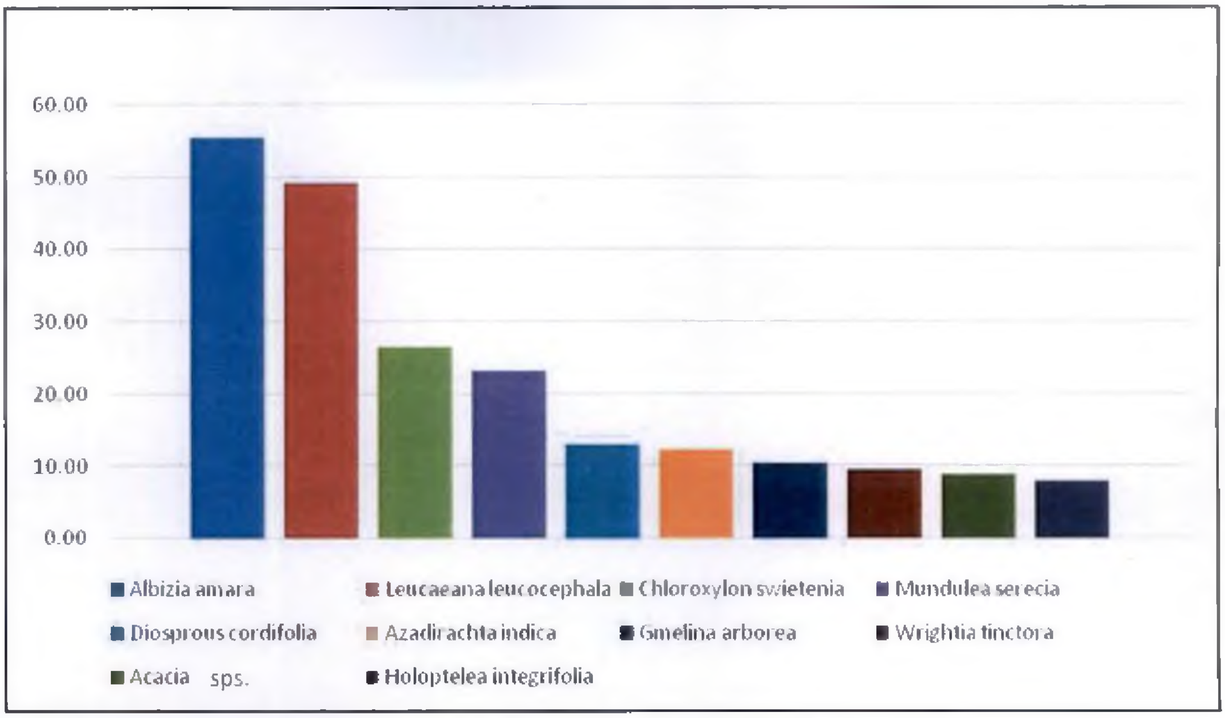



Fig. 17. Important value index (IVI) of major tree species in the plantation area

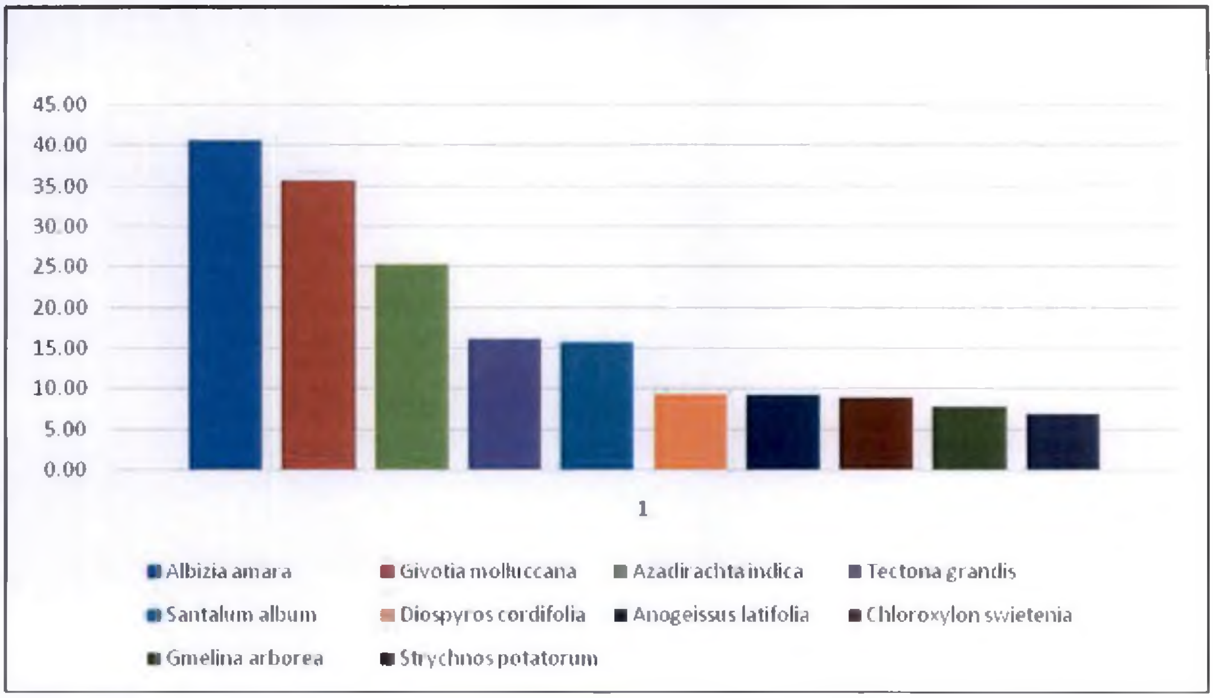



Fig. 18. Important value index (IVI) of major tree species in the biomass conservation area

Studies have shown that plantations can facilitate, or `catalyze', forest succession in their understories, on sites where persistent ecological barriers to succession would otherwise prelude recolonization by native forest species. Plantations have potential to catalyze changes in understory microclimatic conditions, increased vegetation structural complexity, and development of litter and humus layers that occur during the early years of plantation growth. These changes together with increased seed inputs from native forest trees by seed dispersal, suppression of grasses or other light-demanding species that normally prevent tree seed germination or seedling survival, and improved light, temperature and moisture conditions for seedling growth can lead to successful eco-restoration works. With promotion of understory regeneration from native trees, a near monospecific plantation system can be replaced by a mixed forest comprised of the planted species and an increasing number of early and late successional species (Parrotta et al., 1997). Eventually, if the planted species are short-lived and light-demanding, they may disappear entirely from the system, leaving a floristically rich secondary forest. This however can happen only if the planted species do not show weed potential by regenerating profusely affecting regeneration of native vegetation. Alternatively, if the planted trees are gradually removed without removing the woody understory regeneration, a secondary forest could develop quickly. In contrast, short lived pioneer species can reach adult age, die quickly after leaving unfavourable conditions for non-pioneer species establishment too (Barbosa et al., 2003).

Floristic diversity studies revealed that species richness was higher in biomass area compared to plantation area. For example, when compared between Sambarcode plantation and BCA, it was found that species richness (Simpson's diversity index) for plantation was 0.88 while it was 0.95 for BCA. Study conducted by Vidyasagaran and Anilkumar (2009) in the same area observed maximum species richness of 0.96 in biomass area. Floristic diversity studies on vegetation revealed that Sambarcode BCA had the highest species richness (Simpson index 0.95). Species richness between plantations varied significantly. Simpson index obtained in our study varied from 0.73 to 0.86 in plantations. In drier tracts species density was lower in comparison to wetter tracts, where probably the extent of damage is not as severe.

Vegetation structure, species diversity, and ecosystem processes are indicators for monitoring restoration success (Dorren *et al.*, 2004). Measures of vegetation structure provide information on habitat suitability, ecosystem productivity, and help to predict successional pathways (Wang *et al*, 2004). It can be seen from the present study that the floristic diversity of the area was maximum in BCA's of wetter areas, followed by BCA of drier tracts, plantations and non-ecorestored areas. As forest develops, new species begin to colonize and recruit thus leading to a gradual accumulation of more species over time (Chazdon, 2008). Hence, it can be assumed that in due course of time with sufficient management interventions, the diversity would be similar in both the plantations and BCA's. In PCA and cluster analysis reveal that the vegetation structure and species composition of study site was influenced by climate. The wetter regions like Sambarcode, Palliyara and Agali performed well compared to the drier regions.

Table 25. Comparison of important tree species in plantation based on IVI

| Species | Agali | Melechavadiyoor | Palliyara | Pattimalam | Sambarcode | Vellamari | Kottathara |
|---|---|---|---|---|---|---|---|
| *Acacia sps.* | | | 12.19 | | 18.17 | 12.24 | |
| *Acacia leucophloea* | | | | 5.99 | | | |
| *Acacia planifrons* | | | | 8.85 | | | |
| *Acacia polycantha* | | | 35.89 | | | | |
| *Acaia ferruginea* | 23.26 | | | | 14.06 | 7.75 | |
| *Albizia amara* | 18.45 | 68.46 | 60.44 | 67.29 | | 99.1 | 73.2 |
| *Albizia lebbeck* | 8.90 | | | | | | |
| *Albizia procera* | 8.30 | | | | | 14.28 | |
| *Azadirachta indica* | | 12.83 | 27.19 | | 23.24 | 11.93 | |
| *Cassine paniculata* | 11.03 | | | | | | |
| *Chloroxylon swietenia* | | 16.30 | | 28.33 | 48.83 | 33.37 | 58.19 |
| *Dichrostachys cinerea* | | | | | | | 8.28 |
| *Diospyros cordifolia* | | 19.21 | 12.21 | 16.29 | 10.25 | | 21.99 |
| *Dodonaea viscosa* | | | | 6.23 | | | |
| *Erythroxylum monogynum* | | 17.36 | | | | 17.55 | 6.73 |
| *Eucalyptus tereticornis* | | 46.15 | | | | | |
| *Flueggea virosa* | | 9.21 | | | | | |
| *Givotia moluccana* | | | | | 9.89 | | |
| *Gmelina arborea* | | | | 17.15 | 12.24 | 13.61 | 17.24 |

| Species | Agali | Melechavadiyoor | Palliyara | Pattimalam | Sambarcode | Vellamari | Kottathara |
|---|---|---|---|---|---|---|---|
| *Holoptelea integrifolia* | | 12.70 | 22.37 | | 11.42 | | |
| *Leucaena leucocephala* | 66.41 | | 112.32 | 61.83 | 75.79 | 27.47 | |
| *Morinda pubescens* | | | | | | | 9.83 |
| *Mundulea sericea* | | | | 48.74 | | 11.18 | 86.02 |
| *Naringi crenulata* | 8.69 | | | | | | 7.31 |
| *Pleiospermium alatum* | | 10.04 | | | | | |
| *Santalum album* | 16.94 | | | | | | |
| *Sapindus emarginatus* | | 14.97 | | | | | |
| *Senna siamea* | 21.86 | | | | | | 8.65 |
| *Strychnous potatorum* | | | 17.60 | | 10.16 | | |
| *Tamarindus indica* | | | 30.96 | | | | |
| *Wrightia tinctoria* | 9.92 | | 38.13 | 5.79 | | | |

Table 26. Comparison of important tree species in biomass area based on IVI

| Species | Sambarcode | Palliyara | Kottathara |
|---|---|---|---|
| *Acacia ferruginea* | | 11.16 | |
| *Albizia amara* | 11.97 | | 107.83 |
| *Albizia lebbeck* | 12.2 | | |
| *Albizia odorattisima* | 11.27 | | |
| *Albizia procera* | | | 6.98 |
| *Anogeissus latifolia* | | 19.46 | |
| *Azadirachta indica* | | 8.61 | 49.48 |
| *Cassine paniculata* | | 6.62 | |
| *Chloroxylon swietenia* | 20.87 | | |
| *Diospyros cordifolia* | | | 19.73 |
| *Dodonaea viscosa* | | | 6.16 |
| *Erythroxylum monogynum* | | | 17.42 |
| *Givotia molluccana* | 64.8 | 41.84 | |
| *Gliricidia sepium* | | | |
| *Gmelina arborea* | | | 17.07 |
| *Grewia tiliifolia* | | 12.08 | |
| *Leucaena leucocephala* | | | 7.94 |
| *Mundulea sericea* | | | 11.33 |
| *Narengi crenulata* | | | |
| *Peltophorum pterocarpum* | 11.81 | | |
| *Prosopis juliflora* | 12.96 | | |
| *Santalum album* | | 46.11 | |
| *Senna siamea* | | | 8.99 |
| *Strychnos potatorum* | 9.8 | 6.68 | |
| *Tamarindus indica* | | | |
| *Tectona grandis* | | 37.49 | |
| *Wrightia tinctora* | 12.57 | | |
| *Ziziphus mauritiana* | | 7.5 | |

## 5.2. Regeneration Studies

### 5.2.1. Species composition of regeneration in the study area

Regeneration status of area and the life histories of the dominant regenerating populations can indicate future community structure and species composition in the area. The study revealed that average regeneration in plantation was 2.42 individuals /$m^2$, while in biomass areas it was 2.11 individuals /$m^2$. This is generally acceptable as a normal pattern. For example, Parrotta (1997) observed the understory floristic composition of 10 year old restoration forests on a bauxite mined site in Amazonia, where it was observed that the average regeneration density accounts to 2.80–2.88 individuals/$m^2$. In non-eco-restored (NER) areas, the regeneration was found to be low (0.47 individuals/$m^2$) in comparison to ecorestored areas (plantations and BCA) which shows that eco-restoration played an important role in providing better environment for the growth and establishment of the recruitment. Lower regeneration of some of the species might be due to the cumulative effects of the disruption of key ecological process such as pollination and seed dispersal in association with human induced disturbances (Anitha *et al.*, 2010), or absence of seed production due to young age of vegetation in plantations or stress.

In plantations, tree species like *Leucaena leucocephala, Albizia amara, Chloroxylon sweitenia, Mundulea sericea, Erythroxylum monogynum* and *Gmelina arborea* were found both in above ground vegetation and regeneration (Fig. 19). Species composition of regeneration reveals that pioneer species like *Leucaena leucocephala, Albizia amara, Senna siamea* and *Mundulea sericea* were most abundant in plantations. Pioneer species often have high regeneration rate since it produce large number of small seeds that can be easily dispersed. Pioneers are also characterised by seeds had the potential to germinate in difficult circumstances (Otto, 2000).

On cluster analysis it was revealed that Agali, Palliyara and Sambarcode plantations along with Sambarcode BCA formed clusters away from others indicating a higher overall regeneration. PCA analysis indicated that Kottathara BCA was closer to Sambarcode and Palliyara plantations, while Palliyara BCA and Sambarcode BCA was more similar to Agali plantation. These areas were located in the wet tracts of Attappady and are highly conducive for profuse regeneration of the seedlings. Especially in the case of pioneer species which has the innate potential for high regeneration due to high rate of seed production. On the contrary, plantations like Pattimalam, Vellamari and Melechavadiyoor had low regeneration (Table 27). All the NER's were clustered as a group in PCA analysis, the plantation other than Agali, Sambarcode, Palliyara and Kottathara formed a group. The reason for lower regeneration can be attributed to edaphic and biotic constraints probably due to their location near human settlements. Seedlings may be removed by grazing and browsing, advanced growth and saplings are often collected by people for other purposes such as props and firewood. Thus the regeneration aspect of restored area which is the key to the sustainability of the system could be threatened by human interferences. The constraints in the form of grazing and collection, probably could not be negated by the present eco-restoration management. In dry tropical forest, grazing was detrimental to seedling recruitment of most species and could potentially shift the composition of soil seed bank in favour of weedy grasses and herbs (Khurana and Singh, 2001).

Some exotic species used for eco-restoration acted as invasive species invading other natural stands. *Leucaena leucocephala* seems to have high weed potential, since these species planted in the Palliyara plantations were also found to be high in Palliyara BCA in the form of regenerations, where it was never planted (Fig. 20). This may eventually degrade the stands as well as destroy its species diversity. So precaution is advised when using exotic species as a planting stock for eco-restoration programme, especially if they are invading species. Hence, present study indicates that native species are recommended as well as a safe option for eco-restoration programme over an exotic one.

Agali plantation had good regeneration of *Santalum album*. *Santalum album* is a species that can regenerate through root suckers and hence can potentially colonise an area. Moreover, these areas were protected well from both anthropogenic interferences and animals.

PCA and cluster analysis revealed that regeneration was lesser in drier and disturbed area. While, higher regeneration occurred in the wetter and undisturbed area. Similarity index between vegetation and regeneration were higher. It can be explained that seed rain and vegetative propogation contribute to regeneration.

The results from Palliyara, Sambarcode and Agali plantation showed that regeneration of *Leucaena leucocephala* in these regions was heavy. This can be explained because of profuse seeding or seed rain. Supporting the present study, Campos and de Souza (2003) found that seed rain played a larger role in rainforest regeneration than the soil seed bank. In addition, Benitez-Malvido et al. (2001) noted that the seed rain contributed more late successional species than the seed bank in primary rainforests and pastures, and the seed bank contributed more early successional species than the seed rain in secondary rainforests.

Table 27. Location wise comparison of regeneration based on relative density in plantation area

| Species | Vellamari | Melecha-vadiyoor | Palliyara | Pattimalam | Sambarcode | Agali | Kottathara |
|---|---|---|---|---|---|---|---|
| *Acacia leucophloea* | | | | 1.64 | | | |
| *Acacia planifrons* | | | | | | | 53.98 |
| *Albizia amara* | 9.05 | 15.75 | 1.05 | 27.05 | 1.77 | | 1.33 |
| *Albizia procera* | | | 1.4 | | | | |
| *Azadirachta indica* | 5.88 | | 0.52 | | 2.28 | | |
| *Bauhinia racemosa* | | | | | | 1.22 | |
| *Bombax cieba* | | | | | | 1.22 | |
| *Canthium coromandelicum* | 2.71 | | | | | | |
| *Catunaregam spinosa* | | 17.32 | | | | | 2.27 |
| *Chloroxylon swietenia* | 5.88 | | | 4.92 | 9.62 | | 8.71 |
| *Commiphora berryi* | | 3.15 | | | | | |
| *Cordia monoica* | | | | | | | 0.95 |
| *Dichrostachys cinerea* | | | | | | | 0.95 |
| *Diospyros cordifolia* | | 3.15 | 1.92 | 9.02 | 1.27 | 4.35 | 1.33 |
| *Dodonaea viscosa* | 22.62 | | | 2.46 | | | |
| *Erythroxylum monogynum* | 3.17 | 14.17 | | | | | |
| *Flueggea virosa* | | 7.87 | | | | | |
| *Gmelina arborea* | 3.62 | 3.15 | | 4.1 | 4.05 | | |
| *Holoptelea integrifolia* | | | 1.57 | | | | |
| *Jacaranda mimosifolia* | | | 0.52 | | | | |
| *Leucaena leucocephala* | 31.67 | | 88.29 | 15.57 | 73.42 | 68.87 | |
| *Mundulea sericea* | 8.6 | 10.24 | | 25.41 | | | 28.03 |
| *Murraya koenigii* | 4.07 | 7.87 | | | | | |
| *Naringi crenulata* | | | | | | 2.09 | |
| *Pleiospermium alatum* | | | | | | 1.04 | |
| *Pongamia pinnata* | | | | | 1.01 | | 0.57 |
| *Santalum album* | | | | | | 9.22 | |

| Species | Vellamari | Melecha-vadiyoor | Palliyara | Pattimalam | Sambarcode | Agali | Kottathara |
|---|---|---|---|---|---|---|---|
| *Sapindus emarginatus* | | 3.94 | | | | | |
| *Senna auriculata* | | | | 3.28 | | | |
| *Senna siamea* | | | | 2.46 | 0.76 | 0.87 | 1.14 |
| *Strychnos potatorum* | | | 1.4 | | 1.27 | | |
| *Tamarindus indica* | | | 0.7 | | | | |
| *Wrightia tinctoria* | | | | | | 0.87 | |
| *Ziziphus mauritiana* | | | 0.87 | | 2.28 | 7.65 | |

Table 28. Location wise comparison of important regenerated species in biomass area

| Sl No | Species | Palliyara | Sambarcode | Kottathara |
|---|---|---|---|---|
| | | RD | RD | RD |
| 1 | *Acacia leucocephala* | | 3.9 | |
| 2 | *Albizia amara* | | 1.77 | 2.78 |
| 3 | *Azadirachta indica* | | 2.84 | 28.89 |
| 4 | *Bombax ceiba* | 2.56 | | |
| 5 | *Canthium coramandelica* | | | 2.78 |
| 6 | *Chloroxylon swietenia* | | 15.25 | |
| 7 | *Commiphora berryi* | | | 2.22 |
| 8 | *Diospyros cordifolia* | | | 6.11 |
| 9 | *Dodonaea viscosa* | 7.26 | | 5 |
| 10 | *Erythroxylum monogynum* | | | 7.78 |
| 11 | *Flueggea virosa* | | | 3.33 |
| 12 | *Gmelina arborea* | | 4.96 | |
| 13 | *Grewia tiliifolia* | | 2.84 | |
| 14 | *Leucaena leucocephala* | 3.42 | 45.39 | 24.44 |
| 15 | *Morinda pubescens* | | | 9.44 |
| 16 | *Murraya koenigii* | 2.35 | | |
| 17 | *Phyllanthus emblica* | 2.78 | | |
| 18 | *Santalum album* | 30.13 | | |
| 19 | *Schefflera wallichiana* | 2.35 | | |
| 20 | *Senna auriculata* | | 3.19 | |
| 21 | *Strychnos potatorum* | | 2.13 | |
| 22 | *Tamarindus indica* | 3.85 | | |
| 23 | *Tectona grandis* | 3.63 | | |
| 24 | *Ziziphus mauritiana* | 20.03 | 4.61 | |

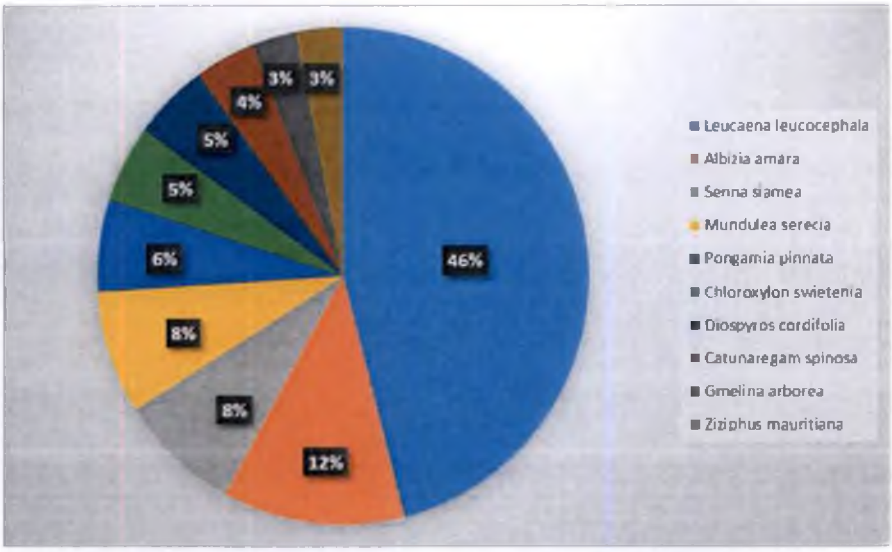



Fig. 19. The abundance (A) of species regeneration in Plantation area

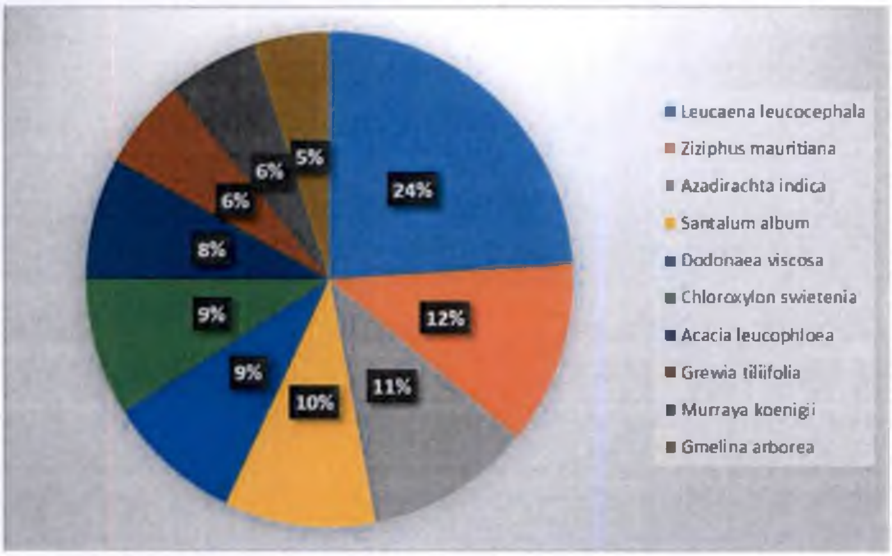



Fig. 20. The abundance (A) of species regeneration in Biomass area

### 5.3. Soil seed bank studies

#### 5.3.1. Species composition and seed density in the study area

The present study on seed banks in Attappady revealed the mean seed density of the study area to be 153.3 seeds/m$^2$ (Table 18). The mean seed density of plantations was 176.8 seeds/m$^2$. Seed density for BCA was estimated to be 247.4 seeds/m$^2$ while that for NER was recorded as 35.6 seeds/m$^2$. Maximum seed bank size was observed in Sambarcode plantation (455 seeds/m$^2$), where as in Vellamari NER, seed bank was absent. The range of seed bank size in plantations varied from 455.6 seeds/m$^2$ to 51.11 seeds/m$^2$. The seed bank size in BCA's ranged from 380.0 seeds/m$^2$ to 111.1seeds/m$^2$, while that of NER ranged from 66.67 seeds/m$^2$ to nil. Thus it is evident that there exists a wide variation in the seed bank constitution among the sites studied. It is also evident that the seed banks of BCA were more established than plantations and NER areas. These values for plantations are more or less in tune with several observed studies elsewhere. For example, study conducted by Liebenman (1979) in dry forest of Ghana observed a maximum seed density of 160 seeds/m$^2$. Perera (2005) has observed soil seed density of 166 $\pm$ 127 seeds/m$^2$ from tropical semi deciduous forest of Srilanka. Paschoal (2004) studied the soil seed bank in a seasonal semi deciduous forest in Brazil and found an average density of 297 seeds/m$^2$. Seed bank sizes of considerable lower sizes too have been observed. For example seed density of early and late successional moist deciduous forests were found to be 47.2 and 69.2 seeds /m$^2$, respectively, (Nave, 2005). Generally, low seed density in the soil seed banks may be related to the relatively lesser species present in the vegetation, as soil seed banks reflect the vegetation to some degree (Pugnaire and Lazaro, 2000). Yuan *et al.*, (2012) conducted a study in Quinghai-Tibetan plateau and found out that seed density increased with decreasing level of degradation, while it increased with age after restoration. The present study agrees to this observation, as the seed bank density observed is the lower in the NER regions where the degradation is maximum and highest in the BCA regions where the degradation is less. Moreover BCA represent stands with older plants compared to plantations. Seed persistence in soil is also related to microsite conditions that partially regulate seed germination or dormancy (Reuss *et al.*, 2001). As plantations mature, the increasingly shaded conditions of the understory would inhibit germination of light requiring species. From the present study, it is evident that the plantations are placed in between the NER and BCA in terms of seed density.

*Leucaena leucocephala* was the dominant tree species represented in seed bank (Fig. 22). Other tree species found in the study were *Albizia odoratissima, Samanea saman, Santalum album, Erythroxylum monogynum and Senna siamea. Albizia amara* were absent in the soil seed bank, this may be due to unfavourable germination conditions persisting in the area. Most of the trees species present in the vegetation were thus non-represented in the seed bank. Consistent with other studies herbaceous species dominated the soil seed bank in the study area (Fig. 23). Herbaceous seeds make up to 50% of the total seeds in the soil seed bank. Soil seed banks of young successional forests are generally dominated by agricultural weeds, and their seeds were mainly dispersed by wind. Therefore, such seed banks do not often contribute to the forest regeneration (Perera, 2005). Herbaceous seeds in the soil remain viable for longer periods than other seed types (Ghersa and Martinez-Ghersa, 2000). Thus the present study indicates that the seed bank of Attappady region is dominated by one tree species, *Leucaena leucocephala* which is showing tendencies to invade areas and probably become a weed disrupting the normal succession in this area.

Soil seed banks are important for these eco-restored areas, especially in case of some unforeseeable events that may heavily impact the above ground vegetation as they will be the only source for its natural re-establishment. Soil seed banks play a major role in natural regeneration after disturbances such as fire, logging and overgrazing in humid environments and determining the composition and density of seed banks is considered as an essential step in artificial restoration of degraded vegetation (Van der Valk and Pederson, 1989). In present study, the eco-restored plantations are still young and as such it does not contribute much to the soil seed bank.

The cluster analysis on soil seed bank shows that Melechavadiyoor, Palliyara NER and Palliyara BCA formed a cluster different from the rest of the plots in Attappady. The reason for the close relationship between Palliyara NER and BCA can be attributed to the fact that the nearby vegetation was acting as the seed source for its corresponding NER. Palliyara NER is the only observed NER which has a viable soil seed bank. The reason for the absence of a viable soil seed bank in other NER's can be attributed to the fact that unlike Palliyara NER, these NER's does not have any good surrounding seed source apart from the high level of degradation. Parrotta *et al.* (1997) observed that the relative catalytic effect of plantations increases with increased site degradation and from drier to wetter sites, and generally decreases with increasing distance from remnant native forest stands (seed sources).

Study revealed that seed bank differs with seasonal change. In present study, most of the seeds germinated in pre monsoon followed by monsoon periods (Fig. 21). This may be explained by the higher rates of seed dispersal during the dry season in deciduoud forest. Another factor that may explain these seasonal differences is that the conditions are favourable for germination during the warm and rainy summer. Chandrashekara *et al.* (1993) observed that the density of germinable seeds in a humid forest seed banks of Western Ghats of Kerala, fluctuates considerably with time of the year, and the seed density was high during the monsoon season. Many dominant species, including some overstory species, were found absent from the soil seed banks. Previous research has shown that existence and persistence of seeds in the soils are partially influenced by seed production and intrinsic attributes of seeds (Luzuriaga *et al.* 2005).

Soil seed bank diversity (Shannon Weiner index) of study area was found to be very low ranging from 0 to 0.98 (Table 22). Seed bank diversities of 1.34 to 2.09 has been observed from tropical dry forests (Pratima, 2012). Present results are in contrast with these. It can be partially attributed to the methodological difference where these authors followed seed separation technique compared to seedling emergence technique. Seedling emergence technique tests only germinable seeds while seed separation technique enumerates all the seeds present in the soil. With many species tends to have dormant seeds, this difference could be substantial in the deciduous forest. Nevertheless, the lower diversity of seed banks in the study area is evident. Species diversity was less observed in soil seed bank compared to above ground vegetation. It can be presumed that if present type of seed bank continues, future vegetation would be changed in its composition. Since, most of tree species are capable of increasing population through vegetative propagation; the scenario could be different too. The richness and diversity of seed bank of Palliyara plantation was very low because of dense infestation of *Leucaena leucocephala*. Prolonged presence of *Leucaenae leucocephala* seeds has been observed to substantially reduce the diversity of species in seed bank elsewhere too (Navie *et al.*, 1998).

PCA and cluster analysis indicated that soil seed bank density was higher for Sambarcode BCA and plantations, while seed bank diversity was observed higher in Agali plantation. Soil seed bank was poorly developed in the study areas.

Similarities in species composition between the soil seed banks and corresponding vegetation were analysed using Sorensen similarity index. Sorensen similarity index ranges from 0 to 1. The result of Sorensen similarity index worked out in Attappady area (Table 23) showed that similarity index between above ground vegetation and soil seed bank was significantly low with a maximum value 0.14. Low similarity is generally associated with dominance of annuals in the soil seed bank and perennial species in the extant vegetation (Thompson, 1978). A low similarity of species composition between soil seed banks and aboveground vegetation in the degraded area implied that the seed bank contributed little to the restoration of the aboveground vegetation and vice versa. Woody plants representation in soil seed bank are very few suggesting that most woody plants rather use the seed rain, seedling banks or coppicing from stumps as alternative regeneration routes than seed bank. Seed size maybe another factor responsible for the scarcity of many aboveground species in the seed banks, because seed size and seed longevity are often negatively correlated (Bossuyt *et al.*, 2006). Supporting present study, Senbeta and Teketay (2002) found out similarity in species composition of soil seed bank using Jaccards coefficient of similarity index. The authors observed that plantations had lower value compared to natural forests. Wang *et al.* (2009) studied seed bank of plantation and observed Sorensen similarity index for plantations up to 0.48, with the highest value in the Eucalyptus plantation. Present study revealed no difference in similarity index for plantation and biomass area with seed bank. Understanding the similarity of species composition between a seed bank and standing vegetation can provide insight into whether the seed bank is driving vegetation composition, or the vegetation is driving seed bank composition (Leck and Simpson, 1987; Henderson, 1988). Due to a low similarity index in present study, it does not indicate such a relationship existing in the study area.

Seedling bank resulting from seed rain seems to be a major role player in vegetation establishment than seed bank. In the present study it is found that proper seed bank was not established as a result of the restoration efforts.

Table 29. Location wise comparison of soil seed bank in study area based on seedlings germinated.

| Location | *Leucaena leucocephala* | *Albizia odoratissima* | *Senna siamea* | *Samanea saman* | *Erythroxylum monogynum* | *Santalum album* |
|---|---|---|---|---|---|---|
| Sambarcode | 326.67 | 31.11 | 6.67 | | | |
| Palliyara | 140 | | | | | |
| Melechavadiyoor | nil | nil | nil | nil | nil | nil |
| Vellamari | 73.33 | | | | | |
| Agali | 55.56 | | | 2.22 | 2.22 | |
| Pattimalam | 73.33 | | | | | |
| Kottathara | 15.56 | | | | | |
| Sambarkode biomass | 240 | 48.89 | | | | |
| Palliyara biomass | 22.22 | | | | | 31.11 |
| Kottathara biomass | 40 | | | | | 6.67 |
| Palliyara ner | | | | | | 55.56 |
| Melechavadiyoor ner | 2.22 | | | | | |

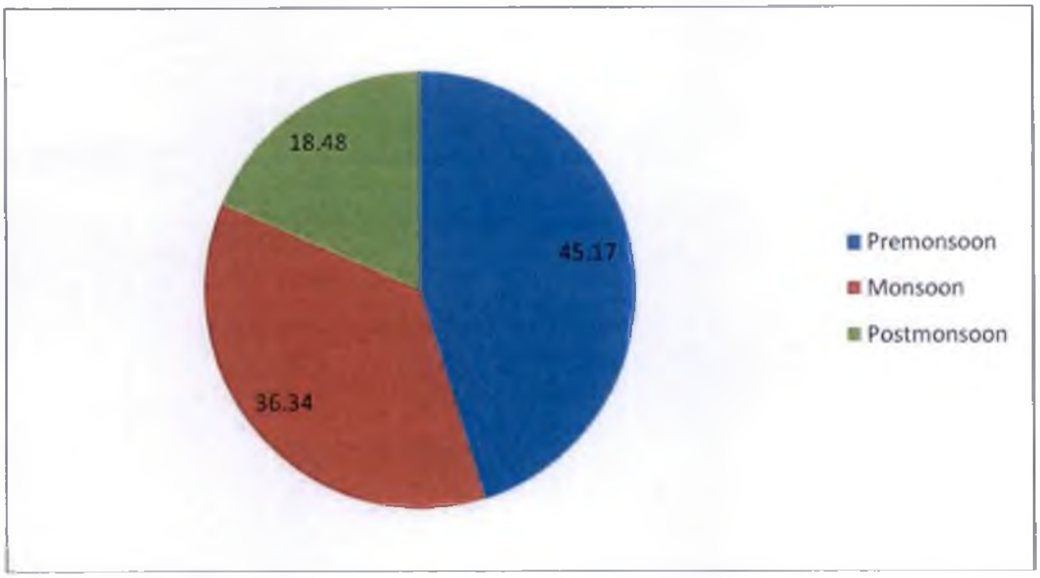



Fig. 21. Season- wise seed bank germination in Eastern Attappady

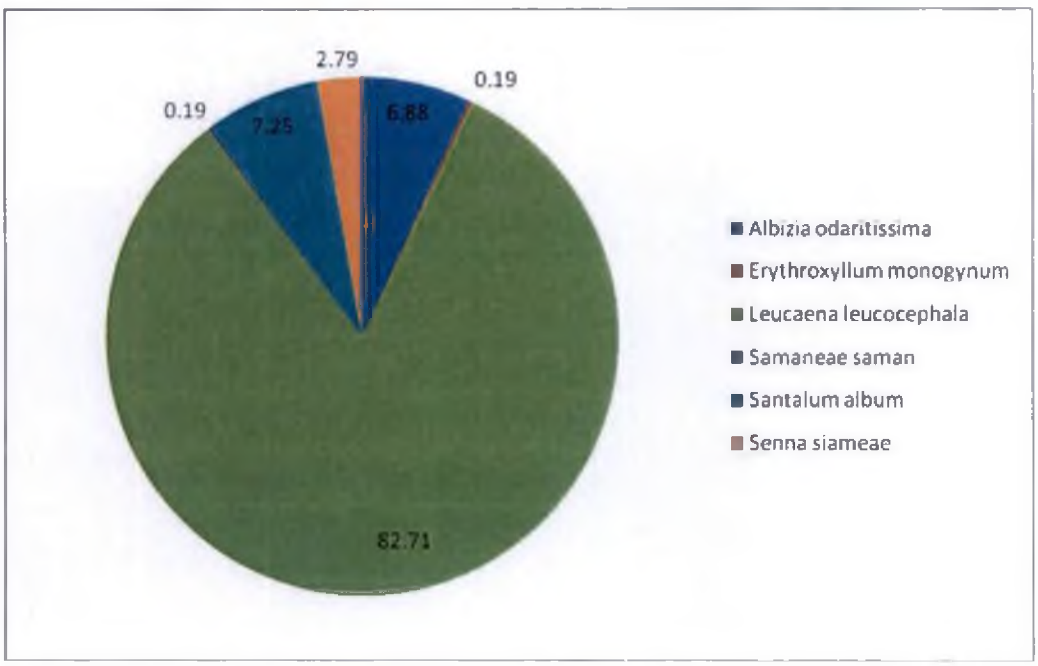



Fig. 22. Tree species represented in soil seed bank of Eastern Attappady

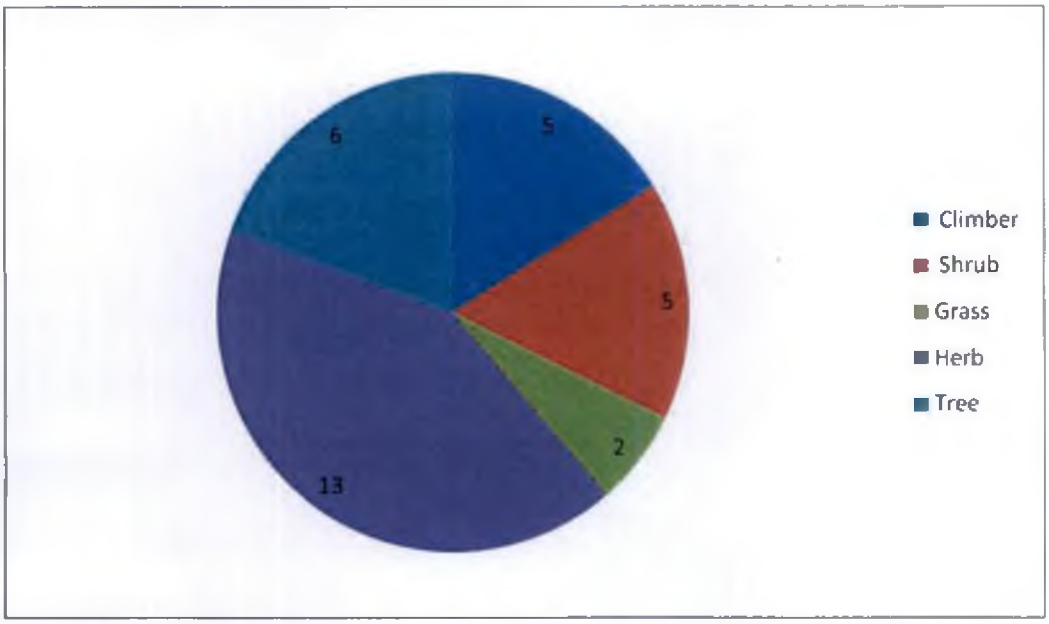



Fig. 23. Habit wise representation in soil seed bank in Eastern Attappady

# SUMMARY

# 6. SUMMARY

The objective of study was to find the impact of ecorestoration on soil seed bank in Eastern Attappady and relate it to the structural attributes of vegetation in the area. Fifteen-sites were randomly selected consisting of seven plantations, five non-ecorestored areas (NER) and three Biomass Conservations Areas (BCA). From each site, above ground vegetation and regeneration were enumerated. In soil seed bank study, five soil samples were collected from each site and seedling emergence technique was conducted. Salient features of the study are summarized below.

1. Altogether ninety species were encountered in the study area. The density of trees in the study sites ranged from 2.5 trees/ha to 515 trees/ha
2. *Leucaena leucocephala* with higher IVI values dominated plantation of wetter regions of Agali (66.41), Palliyara (112.32) and Sambarcode (75.79). In Vellamari, Melechavadiyoor, Pattimalam and Kottathara plantation *Albizia amara* was the dominant species. *Leucaena leucocephala* and *Albizia amara* were predominant because they were pioneer tree species.
3. The present study of biomass and plantation area showed significant differences in species composition and vegetation structure. It was observed that planted tree species like *Leucaena leucocephala, Albizia amara, Senna siamea, Mundulea sericea and Chloroxylon sweitenia* were dominating the plantation
4. Structural analysis of BCA revealed that presence of tree species such as *Albizia amara, Givotia moluccana, Azadirachta indica, Tectona grandis, Diospyros cordifolia, Chloroxylon swietenia* and *Anogeissus latifolia* in Palliyara BCA and Sambarcode BCA constitute moist deciduous forests type
5. Kottathara BCA was significantly different to Palliyara and Sambarcode BCA's, the reason for the difference can thus be attributed to the lower

moisture regimes. So it's assumed that the rainfall regime of the region is one of the main driving forces for this vegetation structure.

6. Cluster analysis of above ground vegetation revealed that Palliyara and Sambarcode BCA's and Agali plantation were found to be the most distant cluster from the rest of the study area. These areas fall are in the wetter tracts of Attappady
7. In cluster analysis plantations at Pattimalam, Kottathara and Vellamari were proximal to NER clusters which indicated that the eco-restoration is poorly performing in these areas. These plantations fall in the drier tracts of Attappady.
8. Floristic diversity studies revealed that species richness was higher in biomass area compared to plantation area. Comparing Sambarcode plantation and BCA, it was found that species richness (Simpson's diversity index) for plantation was 0.88 while it was 0.95 for BCA.
9. Species richness between plantations varied significantly. Simpson index obtained varied from 0.73 to 0.86 in plantations.
10. Floristic diversity of the area was maximum in BCA's of wetter areas, followed by BCA of drier tracts, plantations and non-ecorestored areas. In drier tracts species density was lower in comparison to wetter tracts.
11. Regeneration study revealed that average regeneration in plantation was 2.42 individuals $/m^2$, while in biomass areas it was 2.11 individuals $/m^2$. In non-eco-restored (NER) areas, the regeneration was found to be low 0.47 individuals$/m^2$
12. Lower regeneration of some of the species could be due to stress, lack of pollination agents and seed dispersal mechanisms in association with human induced disturbances or absence of seed production due to young age of vegetation in plantations.
13. Cluster analysis revealed that Agali, Palliyara and Sambarcode plantations along with Sambarcode BCA formed clusters away from others indicating a

higher overall regeneration. On the contrary, plantations like Pattimalam, Vellamari and Melechavadiyoor had low regeneration. The reason for lower regeneration can be attributed to edaphic and biotic constraints probably due to their location near human settlements.

14. Some exotic species *Leucaena leucocephala* seems to have high weed potential and it may degrade the stands as well as destroy its species diversity. Native species are recommended as a safe option for eco-restoration programme over an exotic one.
15. Seed bank study revealed that mean seed density of plantations area was 176.8 seeds/$m^2$. Seed density for BCA was estimated to be 247.4 seeds/$m^2$ while that for NER was recorded as 35.6 seeds/$m^2$.
16. The range of seed bank size in plantations varied from 455.6 seeds/$m^2$ to 51.11 seeds/$m^2$. The seed bank size in BCA's ranged from 380.0 seeds/$m^2$ to 111.1seeds/$m^2$, while that of NER ranged from 66.67 seeds/$m^2$ to nil.
17. Seed bank density observed was lowest in the NER regions where the degradation is maximum and highest in the BCA regions where the degradation is less.
18. The cluster analysis on soil seed bank shows that Melechavadiyoor NER, Palliyara NER and Palliyara BCA formed a cluster different from the rest of the plots in Attappady. The reason for the close relationship between Palliyara NER and BCA can be attributed to the fact that the nearby vegetation was acting as the seed source for its corresponding NER.
19. Study revealed that seed bank differs with seasonal change. In present study, most of the seeds germinated in pre monsoon followed by monsoon periods.
20. Soil seed bank diversity (Shannon Weiner index) of study area was found be ranging from 0 to 0.98. Species diversity was less in soil seed bank compared to above ground vegetation. It can be presumed that if present type of seed bank persists, vegetation would be changed in its composition in future.

21. The richness and diversity of seed bank of Palliyara plantation was very low because of dense regeneration of *Leucaena leucocephala*.
22. Sorenson similarity index worked out in study area showed that similarity index between above ground vegetation and soil seed bank was significantly low with a maximum value 0.14.
23. Seedling bank resulting from seed rain seems to be a major role player in vegetation establishment than seed bank. In the present study it is found that proper seed bank was not established as a result of the restoration efforts.

# References

## REFERENCES


Abdella, M., Tamrat, B., and Sileshi, N. 2007. Soil seed bank analysis and sites description of the Afro-alpine vegetation of Bale Mountains, Ethiopia. *Acad Sci. Publ.* 19: 279-387.

Anitha, K., Joseph, S., Chandran, R. J., Ramasamy, E. V., and Prasad, N. S. 2010. Tree species diversity and community composition in a human-dominated tropical forest of Western Ghats biodiversity hotspot, India. *Ecol. Complexity* 7: 217-224.

Ashton, P. M. S., Samarasinghe, S. J., Gunatilleke, I., and Gunatilleke, C.V.S. 1997. Role of legumes in release of successionally arrested grasslands in the central hills of Sri Lanka. *Restoration Ecol.* 5:36-43.

Augusto, L., Dupouey J. L., Picard J. F., and Ranger, J. 2001. Potential contribution of the seed bank in coniferous plantations to the restoration of native deciduous forest vegetation. *Acta Oecologica* 22: 87-98.

Baker, H. G. 1989. Some aspects of the natural history of seed banks. In: Leck, M. A., Parker, V. T., and Simpson, R.L. (eds.), *Ecology of soil seed banks*. London academic Press, pp. 5-19.

Barbosa, K. C., and Pizo, M. A. 2006. Seed rain and seed limitation in a planted gallery forest in Brazil. *Restoration Ecol.* 14: 504-515.

Basha, S. C. 1987. *Studies of ecology of evergreen forests of Kerala with special reference to Silent valley and Attapady.* Ph.D. Thesis. University of Kerala. Trivandrum, 232p.

Benitez-Malvido, J., Martinez-Ramos, M., and Ceccon, E. 2001. Seed Rain vs. Seed Bank, and the effect of vegetation cover on the recruitment of tree seedlings in Tropical successional vegetation. Gerbruder Bortraeger, Berlin, pp.185-204.

Bernhardt, K.G., and Ulbel, E. 2000. The importance of soil seed banks for the conservation of nearly extinct species: insights from *Coleanthus subtilis* (poaceae). University of Natural Resources and Applied Life Sciences, Dept. Int. Biol. Gregor- Mendel-Strasse, Vienna, Austria. 33: 1180.

Bossuyt, B., Butaye, J., and Honnay, O. 2006. Seed bank composition of open and overgrown calcareous grassland soils: a case study from Southern Belgium. *J. Environ. Manage.* 79: 364-371.

Bossuyt, B., and Hermy, N. 2001. Influence of land use history on seed banks in European temperate forest ecosystems: a review. *Ecography* 24: 225-238.

Bossuyt, B., and Hermy, N. 2003. The potential of soil seed banks in the ecological restoration of grassland and heathland communities. *Belg. J. Bot.* 136: 23-34.

Bossuyt, B., and Honnay, O. 2008. Can the seed bank be used for ecological restoration? An overview of seed bank characteristics in European communities. *J. Veg. Sci.* 19: 875-884.

Calegari, L., Leandro, C., Sebastiao, V. M., and Lilian, C. C. 2013. Evaluation of soil seeds bank for forest restoration in Carandai, *M.G. Rev. Arvore.* 37(5): 871-880.

Campos, J. B., and de Souza, M. C. 2003. Potential for natural forest regeneration from seed bank in an upper Parana River floodplain, *Brazil. Braz. Arch. Biol. Technol.* 46: 625-639.

Carmona, R. 1992. Problematic and management of weed seed banks in agricultural soils. *Planta Daninha* 10(1): 5-16.

Carvalho, P. C., and Favoretto, V. 1995. Impacto das reservas de sementes no solo sobre a dinâmica populacional das pastagens. Informativo Abrates 5(1) 87-108.

Champion, H. C., and Seth, S. K. 1968. *A Revised Survey of Forest types of India.* Government of India, New Delhi, 150p.

Chandrashekara, U. M., and Ramakrishnan, P. S. 1993. Germinable soil seed bank dynamics during the gap phase of a humid tropical forest in the western ghats of Kerala, India. *J. Trop. Ecol.* 9: 455-467.

Chazdon, R. L. 2003. Tropical forest recovery: legacies of human impact and natural disturbances. *Perspectives Plant Ecol. Evol. Syst.* 6:51-71.

Chazdon, R. L. 2008. Chance and determinism in tropical forest succession. In: Schnitzer, S.A., Carson, W.P. (eds.), *Tropical Forest Community Ecology.* Wiley-Blackwell Publishing, Oxford, pp. 384-408.

Cheke, A. S., Nanakorn, W., and Yankoses, C. 1979. Dormancy and dispersal of seeds of secondary forest species under the canopy of a primary tropical rain forest in Northern Thailand. *Biotropica* 11: 88-95.

Cook, R. 1980. The Biology of Seeds in the Soil. In 'Demography and Evolution in Plant Populations. In: Solbrig, O. T. (ed.), Blackwell Scientific Publications, Melbourne, pp. 107-129.

Cox, G. W. 1985. *Laboratory Manual of General Ecology* (7th Ed.) Dubuque, IA: WCB, 150p.

Cubina, A., and Aide, T. M. 2001. The effect of distance from forest edge on seed rain and soil seed bank in a tropical pasture. *Biotropica* 33: 260-267.

Curtis, J. T., and Mc Intosh, A. 1950. *The Vegetation of Wisconsin: An Ordination of Plant Communities.* University of Wisconsin Press, Wisconsin, 209p.

Dainou, K., Bauduin, A., Bourland, N., Gillet, J., Feteke, F., and Doucet, J. 2011. Soil seed bank characteristics in Cameroonian rainforests and implications for post-logging forest recovery. *Ecol. Engng.* 37 (10):1499-1576.

Decocq, G. 2004. Soil seed bank composition and diversity in a managed temperate deciduous forest. *Biodiv. Conserv.* 13: 2485:2509.

Devlaeminck, R. 2005. Inflow of seeds through the forest edge: evidence from seed bank and vegetation patterns. *Plant Ecol.* 176: 1-17.

Dorren, L. K. A., Berger, F., Imeson, A. C., Maier, B., and Rey, F. 2004. Integrity, stability and management of protection forests in the European Alps. *For. Ecol. Manage.* 195: 165-176.

Dupuy, J. M., and Chazdon, R. L. 1998. Long-Term Effects of Forest Regrowth and Selective Logging on the Seed Bank of Tropical Forests in Ne Costa Rica. *Biotropica* 30: 223-237.

Elizabeth, A. 2006. Seed banks of Pinyon-Juniper wood lands: The effects of tree cover and prescribed burn. M.Sc. thesis, Reno University of Nevada, USA, 93p.

Enright, N. 1985. Existence of a Soil Seed Bank under Rainforest in New Guinea. *Aust. J. Ecol.* 10: 67-71.

Enright, N. J., and Cameron, E. K. 1988. The soil seed bank of a kauri (*Agathis australis*) forest remnant near Auckland, N. Z. *J. Bot.* 26: 223-236.

Epp, G. A. 1987. The Seed Bank of *Eupatorium odoratum* Along a Successional Gradient in a Tropical Rain Forest in Ghana. *J. Trop. Biol.* 3: 139-149.

FAO. 2010. Global Forest Resources Assessment 2010. Main report. FAO, Rome. 12p.

Fernandez-Quintanilla, C., Saavedra, M. S., and Garcia Torre, L. 1991. *Ecologia de las malas hierbas.* Mundi-Prensa, Madrid, 49-69p.

Forget, P. M., Milleron, T., and Feer, F. 1998. Patterns in post-dispersal seedremoval by Neo-tropical rodents and seed fate in relation to seed size. *J. Ecol.* 177: 5-49.

Fowler, W. M. 2012. Soil seed bank dynamics in transferred top soil-evaluating restoration potential. MSc Thesis, School of Environmental Science, Murdoch University, 158p.

Funes, G., Basconcelo, S., Díaz, S., and Cabido, M. 2003. Seed bank dynamics of *Lachemilla pinnata* (Rosaceae) in different plant communities of mountain grassland in central Argentina. *Ann. Botanici Fennici.* 36:109-114.

Garwood, N. C. 1989. Tropical soil seed banks: A Review. In: Leck, M. A., Parker, V. T., and Simpson, R. L. (eds.), *Ecology of soil seed banks.* pp. 149-210.

Gashaw, M. 2002. Soil seed bank dynamics of fire-prone wooded grassland, woodland and dry forest ecosystems in Ethiopia. *Nord. J. Bot.* 22: 5-17.

Ghersa, C. M., and Martinez-Ghersa, M.A. 2000. Ecological correlates of weed seed size and persistence in the soil under different tilling systems: implications for weed management. *Field Crops Res.* 67: 141-148.

Godefroid, S., Phartyal, S. S., and Koedam, N. 2006. Depth distribution and composition of seed banks under different tree layers in a managed temperate forest ecosystem. *Acta Oecologica* 29: 283-292.

Graham, A. W., and Hopkins, M. S. 1990. Soil Seed Banks of Adjacent Unlogged Rainforest Types in North Queensland. *Aus. J. Bot.* 38: 261-268.

Grime, J. P. 1981. The role of seed dormancy in vegetation dynamics. *Ann. Appl. Biol.* 98: 555-558.

Groves, R. H., and Willis A. J. 1999. Environmental weeds and loss of plant diversity: some Australian examples. *Aus. J. Environ. Manage.* 6: 164-171.

Guariguata, M. R., Rheingans, R., and Montagnini, F. 1995. Early woody invasion under tree plantations in Costa Rica: implications for forest restoration. *Rest. Ecol.* 3: 252-260.

Guevara S. S., and Gomez-Pompa, A. 1972. Seeds from surface soils in a tropical region of Veracruz, Mexico. *J. Arnold Arboretum* 53: 312-335.

Gutterman, Y., Gendler, T., and Huang, Y. 2007. Plant dispersal strategies, seed bank distribution and germination of Negev desert species. *J. Ecol.* 42: 411.

Hall, J. B., and Swaine, M. D. 1980. Seed stocks in Ghanaian forest soils. *Biotropica* 12: 256-263.

Han, J., Ah, R., Eun, S., Joselito, R. B., Yong, K. L., Su, Y. W., Don, K. L., and Pil, S. P. 2012. Comparison of soil seed banks in canopy gap and closed canopy areas between a secondary natural forest and a big leaf mahogany (*Swietenia macrophylla* King) plantation in the Mt. Makiling Forest Reserve, the Philippines. *J. Environ. Sci. Manage.* 1: 47-59.

Harper, J. L. 1977. Population Biology of Plants. Academic Press: London pp.214-238.

Hegazy, A. K., Hammouda, O., Lovett, D. C., and Gomaa, N. H. 2009. Variations of the germinable soil seed bank along the altitudinal gradient in the northwestern Red Sea region. *Acta Ecologica Sinica*, 29: 20-29.

Henderson, C. B. 1988. Spatial and temporal patterns in the seed bank and vegetation of a desert grassland community. *J. Ecol.* 76: 717-728.

Hermy, M., Honnay, O., Firbank, L., Grashof-Bokdam, C., and Lawesson, J. E. 1999. An ecological comparison between ancient and other forest plant species of Europe, and the implications for forest conservation. *Biol. Conserv.* 91: 9-22.

Holthuijzen, A. M. A. and Boerboom, J. H. A. 1982. The *Cecropia* Seed bank in the Surinam Lowland rain forest. *Biotropica* 14: 62-68.

Holzner, W. 1978. Weed Species and Weed Communities. *Vegetatio.* 38:13-20.

Hopfensperger, K. N. 2007. A review of similarity between seed bank and standing vegetation across ecosystems, *Oikos* 116: 1438-1448.

Hopkins M. S., and Graham A. W. 1987. The viability of seeds of rainforest species after experimental soil burials under tropical wet lowland forest in North-Eastern Australia. *Aus. J. Ecol.* 12: 97-108.

Hopkins, M. S., Tracey, J. G., and Graham, A. W. 1990. The Size and Composition of Soil Seed Banks in Remnant Patches of Three Structural Rainforest Types in North Queensland. Australian Journal of Ecology. 15: 43-50.

Howe, H. F. 1986. Seed dispersal by fruit-eating birds and mammals. In: Murray, R. D. (ed.), *Seed Dispersal.* Academic Press, New York pp. 123-189.

India Census, 2001. Office of the registrar General, India 2A Mansingh road, New Delhi- 110 011.

Janzen, D. H. 1970. Herbivores and the Number of Tree Species in Tropical Forests. *Am. Naturalist* 104: 501-528.

Johnson, E. A. 1975. Buried seed populations in the subarctic forest east of Great Slave Lake, Northwest Territories. *Can. J. Bot.* 53: 2933-2941.

Jonasova, M., Hees, V. A., and Prach, K. 2006. Rehabilitation of monotonous exotic coniferous plantations: a case study of spontaneous establishment of different tree species. *Ecol. Engng.* 28:141-148.

Kassahun, A., Snyman H., and Smit G. 2009. Soil seed bank evaluation along a degradation gradient in arid rangelands of the Somali region, eastern Ethiopia. *Agric. Ecosyst. Environ.* 129 (4): 428-436.

Kellman M. 1980. Geographical patterning in tropical weed communities and early secondary successions. *Biotropica,* 12: 34-39.

KFRI. 1991. *Studies on Human Ecology and Eco-restoration of Attapady Valley* (Final report of research project 116/87 and 120/87). KFRI, Peechi, India.

Khurana, E., and Singh, J. S. 2001. Ecology of seed and seedling growth for conservation and restoration of tropical dry forest: a review. *Environ. Conserv.* 28:39-52.

Lang, N. L. 2006. The Soil Seed Bank of an Oregon Montane Meadow: Consequences of conifer encroachment and implications for restoration, M. Sc. thesis, University of Washington, 68p.

Lang, N.L. and Halpern, C. B. 2007. The soil seed bank of a montane meadow consequences of conifer encroachment and implications for restoration. *Can. J. Bot.* 85: 557-569.

Laurance, W. F. 1997. Responses of Mammals to Rainforest Fragmentation in Tropical Queensland: A Review and Synthesis. *Wildlife Research* 24: 603-612.

Leck, M. A., and Simpson, R. L. 1987. Seed bank of a freshwater tidal wetland turnover and relationship to vegetation change. *Am. J. Bot.* 74: 360-370.

Leinonen, T., Sungurov, R., Kolstrom, T., Sokolov, A., Zigunov, A., and Dorosin, A. 2008. Forest regeneration in Northern and Northwestern Russia in

1993-2004 methods, results and development needs. *Forest Ecol. Manage.* 255: 383-395.

Leishman, M. R., and Westoby, M. 1994. Vegetation development and species assemblages in long term reclamation project on mine spoil. *Funct. Ecol.* 12: 480-485.

Li, H.Y., Mo, X. Q., and Hao, C. 2005 A review of study on soil seed bank in the past thirty years. *Ecol. Environ. Sci.* 18 (2): 731-737.

Li, Y. L. 2009. Floristic composition of vegetation and the soil seed bank in different types of dunes of Kerqin steppe. *Arid Land Res. Manage.* 18: 283-293.

Lieberman, D. 1979. Dynamics of Forests and Thicket on the Acer Plains, Ghana. Ph.D. Thesis, University of Ghana, Legon, Ghana, 250p.

Liu, M., Jiang, G., Yu, S., Li, Y., and Li. G. 2009. The role of soil seed banks in natural restoration of the degraded Hunshandak Sandlands, Northern China. *Restoration Ecol.* 17:127-136.

Luzuringa, A.L., Escudero, A., Olano, J.M., and Loidi, J., 2005. Regenerative role of seed banks following an intense soil disturbance, *Acta Oecol.*, 27: 57-66.

Ma, M., Zhou, X., and Du, G. 2010. Role of soil seed bank along a disturbance gradient in an alpine meadow on the Tibet plateau, *Flora* 205 (2): 128-134.

MacKay, D. B. 1972. The Measurement of Viability. In: Mayer, A. M. and Poljakoff, M.A. (eds.), Viability of Seeds (4th Ed, 1989). The Germination of Seeds, Pergamon Press, Sydney, pp.172-208.

Mansourian, S. 2005. Overview of forest restoration strategies and terms. In: Mansourian, S., Vallauri, D., Dudley, N. (eds.), Forest restoration in landscapes: beyond planting trees. Springer, New York, USA:8–13pp.

Martins, A. M., and Engel, V. L. 2007. Soil seed banks in tropical forest fragments with different disturbance histories in southeastern Brazil. *Ecol. Engng.* 31 (3): 165-174.

Mayer, A. M., and Poljakoff-Mayber, A. 1989. The Germination of Seeds, Fourth Edition. Pergamon Press: Sydney.

Miranda, M., Dieperink, C., and Glasbergen, P. 2007. Costa Rican environmental service payments: the use of a financial instrument in participatory forest management. *Environ. Manage.* 38: 562–571.

Mukhongo, J. N., Kinyamario, J. I., Chira, R. M., and Musila, W. 2011. Assessment of soil seed bank from six different vegetation types in Kakamega forest, Western Kenya. *Afr. J. Biotech.* 10(65): 14384-14391.

Murphy, P. G., and Lugo, A. E. 1986. Ecology of tropical dry forest. *A. Rev. of Ecol. and Syste.* 17:67–88.

Murray, K. G. 1988. Avian seed dispersal of three Neotropical gap dependent plants. *Ecol. Monogr.* 58: 271-298.

Nave, A. G. 2005. Banco de sementes aut ´ octone e al ´ octone, resgate de plantas e plantio de vegetac¸ ˜ao nativa na Fazenda Intermontes, Munic´ıpio de Ribeir ˜ao Grande, SP. PhD Thesis in Forest Resources. University of Sao Paulo-USP, Piracicaba.

Navie, S. C., Panetta, F. D., McFadyen, R. D., and Adkins, S. W. 1998. Behaviour of buried and surface sown seeds of *Parthenium hysterophorus L. Weed Res.* 38: 335-341.

Obiri, J. A., Healey, J. R., and Hall, J. B. 2005. Species representation in the soil seed Bank under two invasive woodland Trees Species. Indicator sand tools for restoration and sustainable management of forests in East Africa. Working Paper. p. 14.

Oke, S. O., Oladipo O.T., and Isichei, A. O. 2006. Seed bank dynamics andregeneration in secondary lowland rainforest in Nigeria. *Int. J. Bot.* 2(4): 363-371.

Ortega, M. and Levassor, C. 1997. Similarity between seed bank and vegetation in Mediterranean grassland: a predictive model. *J. Vegetation Sci.* 9: 815-828.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R. and Anthony, S. 2009. Agroforestree Database: a tree reference and selection guide version 4.0 (http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp)

Otto, H. J. 2000. *Approaches of close to nature Silviculture in Sitka Spruce pioneer plantations in Ireland.* Prosilva, Ireland, 45p.

Parrotta, J. A., Turnbull, J. W., and Jones, N. 1997. Catalyzing native forest regeneration on degraded tropical lands. Forest Ecol. Manage. 99: 1-7.

Paschoal, M. E. S. 2004. Avaliacao da capacidade de regeneracao davegetacao natural em areas dereflorestamento com species de Pinus e Eucalyptus, no munic'ıpio de Agudos. PhD. Thesis (Bot.), Sao Paulo State University, New York, 256p.

Perera, G. A. D. 2005. Diversity and dynamics of the soil seed bank in tropical semi deciduous forests of Sri Lanka. *Trop. Ecol.* 46(1): 65-78.

Pickett, S.T., and McDonnell, M. J. 1989. Seed bank dynamics in temperate deciduous forest. In: Leck, M.A., Parker, V.T., Simpson, R.L. (eds.), *Ecology of Soil Seed Banks.* Academic Press, San Diego, pp. 123-147.

Pratima, K., and Kharae, P. K. 2012. Species diversity in soil seed banks of tropical dry deciduous forest. *Indian forester* 138(8): 737-741.

Pugnaire, F. I., and Lazaro, R. 2000. Seed bank and understorey species composition in a semi-arid environment: the effect of shrub age and rainfall. *Ann. Bot.* 86: 807-813.

Putwain, P. O. and Gillham, D. A. 1990. The significance of dormant viable seed bank in the restoration of heathlands. *J. Biol. Conserv.* 52: 1-16.

Putz, F. E., and Appanah, S. 1987. Buried seeds, newly dispersed seeds, and the dynamics of a lowland forest in Malaysia. *Biotropica* 19:133-152.

Quintana Ascencio, P. F., Gonzalez, E. M., Ramirez, M. N., Dominguez V, G., and Martinez, I. M. 1996. Soil seed banks and regeneration of tropical rain forests from Milpa fields at the Selva Lacandona, Chiapas, Mexico. *Biotropica* 28: 192-209.

Rees, M. 1997. Evolutionary ecology of seed dormancy and seed size. *Philos. Trans. R. Soc. London, B Biol. Ser.* 351: 1299-1308.

Ren, H., Huang, P., Zhang, Q. M., and Hou, C. M. 2002. *Forest Resources and its Ecosystem Service in Guangdong.* Chinese Environ. Sci. Press, Beijing, 118p.

Ren, H., Shen, W., Lu, H., Wen, X., and Jian, S. 2011. Degraded ecosystems in China: status, causes, and restoration efforts. *Landscape Ecol. Engng.* 3: 1-13.

Reuss, S. A., Buhler, D. D., and Gunsolus, J. L. 2001. Effects of soil depth and aggregate size on weed seed distribution and viability in a silt loam soil. *Appl. Soil Ecol.* 16: 209-217.

Richards, P. W. 1996. *The tropical rain forest: An ecological study.* Cambridge University Press, Melbourne, 300p.

Robert, J. C., Diane, L. M., and Randall, J. M. 2000. The demographic role of seed banks. II. Investigation of the fate of experimental seeds of desert mustard *Lesquerella fendleri*. *J. Eco*. 88: 293-302.

Roberts, H. A. 1981. *Seed banks in the soil. Advances in Applied Biology*. Academic Press, Cambridge, 6: 55p.

Rokich, D. P., and K. W. Dixon. 2007. Recent advances in restoration ecology, with a focus on the *Banksia* woodland and the smoke germination tool. *Aus. J. Bot.* 55 (3): 375-389.

Saluei, S. M., and Swaine, M. D. 1988. Rain forest seed dynamics during succession at Gogol, Papua New Guinea. *J. Ecol.* 76: 1133-1152.

Sandrine, G., Shyam, S. P., and Nico, K. 2006. Depth distribution and composition of seed banks under different trees layers in a managed temperate forest ecosystem. Acta *Oecol.* 29: 283 292.

Senbeta, F., and Teketay, D. 2002. Soil seed banks in plantations and adjacent natural dry Afro-montane forests of central and southern Ethiopia. *Trop. Ecol.* 43(2): 229-242.

Sester, M., Durr, C., Darmency, H., and Colbach, N. 2006. Evolution of weed beet (*Beta vulgaris* L.) seed bank: quantification of seed survival, dormancy, germination and pre-emergence growth. *Eur. J. Agron*. 24:19-25.

Shannon, C. E. 1948 A mathematical theory of communication. *The Bell System Technical Journal*, 27:379–423.

Shono, K., Davies, S.J., and Kheng, C.Y., 2006. Regeneration of native plant species in restored forests on degraded lands in Singapore. *Forest Ecol. Manage.* 237: 574-582.

Simpson, E. H. 1949: Measurement of diversity. *Nature*. 15: 163-688.

Simpson, R. L., Leck, M. A., and Parker, V. T. 1989. Seed banks: general concepts and methodological issues. In: Leck, M. A., Parker, V. T., and Simpson, R. L. (eds.), *Ecology of soil seed banks*. London academic press, pp. 3-8.

Sorenson, T. 1948. A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. *Biol. Skr.* 5: 1-34.

Takahashi, K., and Kamitani, T. 2004. Effect of dispersal capacity on forest plant migration at a landscape scale. *J. Ecol.* 92: 778-785.

Teketay, D. 1996. Seed ecology and regeneration in dry Afro-montane Forests of Ethiopia. Ph.D. Thesis, Swedish University of Agricultural Sciences, Umeä, 284p.

Thomas, R. E. 2000. Seed dispersal and forest regeneration in a tropical lowland biocoenosis. PhD thesis, University of Bayreuth, Germany, 225p.

Thompson, K. 1978. The occurrence of buried viable seeds in relation to environmental gradients. *J. Biogeogr.* 5: 425-430.

Thompson, K., and Grime, H. P. 1979. Seasonal variation in the seed banks of herbaceous species in ten contrasting habitats. *J. Ecol.* 67: 893-921.

Thompson, K., Bakker, J. P., and Bekker, R. M. 1997. *Soil seed banks of North West Europe: Methodology, density and longevity*. Cambridge University Press, Cambridge, 202p.

Thompson, K., Band, S. R., and Hodgson, J. G. 1993. Seed size and shape predict persistence in soil, *Funct. Ecol.* 7: 236-241.

Trevor L. M., Neal J. E., Tina L. B., and Sabine, K. 2012. Deforestation strongly affects soil seed banks in eucalypt forests: Generalizations in functional traits and implications for restoration. *Forest Ecol. Manage.* 266: 94-107.

Tucker, N. I. J. 2001. Vegetation Recruitment in a Restored Habitat Linkage in Tropical North Queensland. MSc thesis, James Cook University, 183p.

Tucker, N. I. J. and Murphy, T. 1997. The effects of ecological rehabilitation on vegetation recruitment: some observations from the Wet Tropics of North Queensland. *Forest Ecol. Manage.* 99:202-206.

Uhl, C., and Clark, K. 1983. Seed ecology of selected Amazon basin successional species. *Bot. Gazette* 144: 419-425.

Uhl, C. K., Clark, H., and Murphy, P. G. 1981. Early plant succession after cutting and burning in the upper Rio Negro region of the Amazon Basin. *J. Ecol.* 69: 631-649.

Valbuena, L., and Trabaud, L. 1995 Comparison between the soil seed banks of a burnt and an unburnt *Quercus Pyrenaica* Willd. Forest. *Vegetatio* 119: 81-90.

Valko, O., Torok, P., Tothmeresz, B., and Matus, G. 2010. Restoration potential in seed banks of acidic Fen and dry-Mesophilous Meadows: can restoration based on local seed banks? *Restoration Ecol.* 15: 1-7.

Van der Valk, A. G., and Pedersen, R. L. 1989. Seed banks and the management and restoration of natural vegetation. In: Leck. M. A., Parker, V.T. ans Simpson, R. L. (eds.), *Ecology of soil seed banks*, Academic Press, San Diego, CA, US. pp. 329-346.

Vidyasagaran, K., and Anil kumar, K. A. 2009. Structural Analysis and plant diversity of natural and protected areas of Attappady. Report submitted to AHADS, College of Forestry, Kerala Agricultural University.

Wang, J., Borsboom, A. C., and Smith, G. C. 2004. Flora diversity of farm forestry plantations in southeast Queensland. *Ecol. Manage. Restoration* 5: 43-51.

Wang, J., Ren, H., and Yang, L. 2009. Soil seed banks in four 22-year-old plantations in South China: implications for restoration. *Forest Ecol. Manage.* 258: 2000-2006.

Warr, S. J., Thompson, K., and Kent, M. 1993. Seed banks as a neglected area of biogeographic research: a review of literature and sampling techniques. *Prog. Phys. Geogr.* 17: 329-347.

Wellstein, C., Otte, A., and Waldhardt, R. 2007. Seed bank diversity in mesic grasslands in relation to vegetation type, management and site conditions. *J. Veg. Sci.* 18: 153-162.

White, E., Tucker, N., Meyers, N., and Wilson, J. 2004. Seed dispersal to revegetated isolated rainforest patches in North Queensland. *Forest Ecol. Manage.* 192: 409-426.

Whitmore, T. C. 1983. Secondary succession from seed in tropical rain forests. *For. Abstr.* 44: 767-779.

Whitmore, T. C. 1990. An Introduction to tropical rain forests (2nd Ed.) Oxford University, 124p.

Wodkiewicz, M., and Kwiatkowska, F. A. 2010. Small scale spatial pattern of a soil seed bank in an old growth deciduous forest, *Pol. J. Ecol.* 58 (3): 487-500.

Yorks, T. E. 2000. Vascular plant propagule banks of six eastern hemlock stands in the Catskill Mountains of New York. *J. Torrey Bot. Soc.* 127: 87-93.

Young, J. A., Evans, R. A., Raguse, C. A., and Larson, J. R. 1981. Germinable seeds and periodicity of germination in annual grasslands. *Hilgardia* 49: 1-37.

Yu, S. L., Chen, H.W., and Lang, N. J. 2007. The classification systems of soil seed banks and seed persistence in soil. *Acta Ecol. Sinica* 27 (5): 2099-2108.

Yu, S., Bell, D., Sternberg, M., and Kutiel, P., 2009. The effect of microhabitats on vegetation and its relationships with seedlings and soil seed bank in a Mediterranean coastal sand dune community, *J. Arid Environ.*72 (11): 2040–2053 pp.

Yuan, B.Y., Chen, K.Z., Bowler, J. M., and Ye, S. J. 2012. The formation and evolution of the Qinghai Lake. *Quaternary Sci.* 3: 233-243

Zahran, M. A., and Willis, A. J. 1992. *The Vegetation of Egypt.* Chapman and Hall, London, 200p.

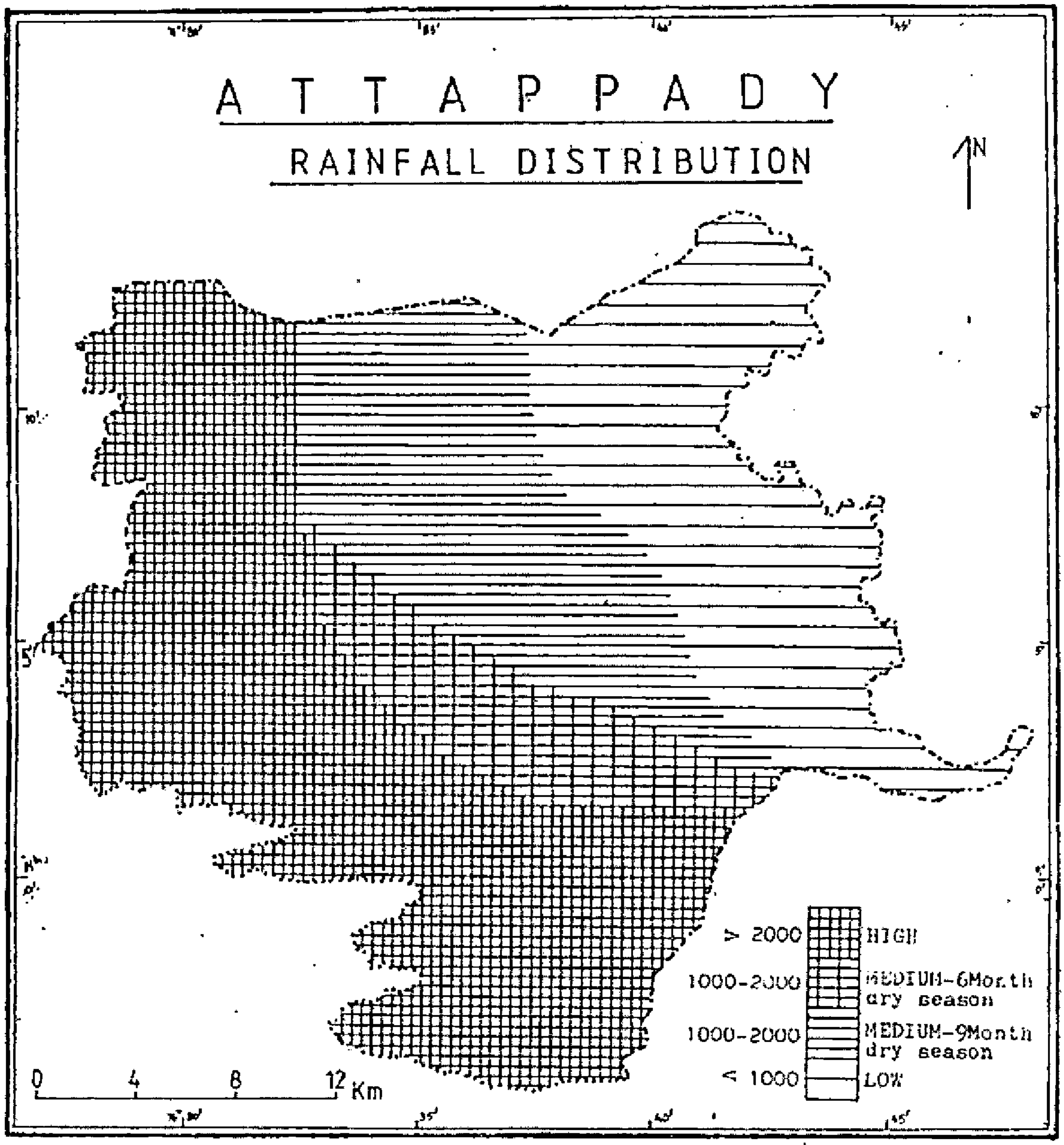
Zheng, H., OuYang, Z. Y., Wang, X. K., and Peng, T. B. 2004. Studies on the characteristics of soil seed banks under different forest restoration types in hilly red soil region, Southern China. *J. Nat. Resour.* 19: 361-368.

Zhou, G. Y., Chen, G. C., Wang, S. Z., and Han, Y. J. 2005. Soil seed banks of *Achnatherum splendens* steppes in the Qinghai Lake area. *Chin. J. Ecol.*, 24 (7): 724-728.

Zhu, Y. J., Dong, M., and Huang, Z. Y. 2005. Effect of sand burial and seed size on seed germination and seedling emergence of *Psammochloa villosa. Acta Phytoecol Sinica,* 29 (5): 730-739.

# APPENDICES

Appendix 1




Rainfall regime of Attappady area (KFRI, 1991)

# IMPACT OF ECORESTORATION ON SOIL SEED BANK IN EASTERN ATTAPPADY, KERALA

By

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## ABSTRACT OF THE THESIS

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## ABSTRACT

A study was conducted to find impact of eco restoration on soil seed bank in Eastern Attappady and relate it to the structural attributes of vegetation in the area. Fifteen sites were randomly selected, which includes three biomass conservation areas (BCA), seven plantation and five non ecorestored sites (NER). From each site, 10 quadrates of size 20 X 20 $m^2$ were selected and vegetation attributes of trees and regeneration enumerated. Soil seed bank sampling was done at an interval of four months in a year. Five soil samples of 30 X 30 $cm^2$ surface area to a depth of 5 cm were collected. To assess the seed density and species composition in the seed banks, seedling emergence technique was used. Sorensen similarity index were calculated to find similarities in species composition between soil seed banks, aboveground vegetation and regeneration.

Rainfall regimes of the region were observed as one of the main driving forces for the vegetation structure. Cluster analysis of above ground vegetation revealed that Palliyara and Sambarcode BCA's and Agali plantation, which fall in the wetter region of the study area were clustered together. Pattimalam, Kottathara and Vellamari plantations which were in drier tract, were proximal to NER clusters. Floristic diversity studies revealed that species richness was higher in biomass area compared to plantation area. Species richness between plantations varied significantly. Simpson index obtained varied from 0.73 to 0.86 in plantations. Floristic diversity of the area was maximum in BCA's of wetter areas, followed by BCA of drier tracts, plantations and non-ecorestored areas.

Regeneration study revealed that average regeneration in plantation was 2.42 individuals/$m^2$, while in biomass areas it was 2.11 individuals/$m^2$. In non-eco-restored (NER) areas, the regeneration was found to be low (0.47 individuals/$m^2$). Cluster analysis revealed that Agali, Palliyara and Sambarcode plantations along with Sambarcode BCA had higher overall regeneration. Plantations like Pattimalam, Vellamari and Melechavadiyoor had low regeneration. The reason for lower regeneration can be attributed to edaphic and biotic constraints probably due to their location closer to human settlements.

Soil seed bank study revealed that mean seed density in the study area was 153.3 seeds/$m^2$. *Leucaena leucocephala, Albizia odoratissima, Senna siamea, Santalum album, Samanea saman* and *Erythroxylum monogymm* were the tree species represented in the soil seed bank. Seed bank was predominated by herbs and shrubs. Seed bank density was observed to be lower in the NER regions, where the degradation is maximum and highest in the BCA regions where the degradation is less. Study revealed that mean seed density of plantations area was 176.8 seeds/$m^2$. Seed density for BCA was estimated to be 247.4

seeds/m$^2$ while that for NER was 35.6 seeds/m$^2$. In soil seed bank, *Leucaena leucocephala* was dominating and with potential to destroy species diversity of the area. Study revealed that seed bank differs with season. In the present study, most of the seeds germinated in pre monsoon followed by monsoon periods. Soil seed bank diversity (Shannon Weiner index) of study area was found to be ranging from 0 to 0.98.

Sorensen similarity index between aboveground vegetation and soil seed bank were low ranging from 0 to 0.14 for study area. Seedling bank resulting from seed rain seems to be a major role player in vegetation establishment than seed bank. The study concluded that evidences of a viable seed bank were not visible as a result of ecorestoration efforts.