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IMPACT OF INVASIVE ALIEN PLANTS ON UNDERSTOREY VEGETATION IN THOLPETTY RANGE OF WAYANAD WILDLIFE SANCTUARY

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **"IMPACT OF INVASIVE ALIEN PLANTS ON UNDERSTOREY VEGETATION IN THOLPETTY RANGE OF WAYANAD WILDLIFE SANCTUARY"** is a bonafide record of research done by me during the course of research and that this 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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DEDICATED TO MY
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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

INTRODUCTION

1. INTRODUCTION

Species which cross over their of natural distribution and get introduced to new habitats are known as alien species (Saxena, 1991). An invasive species as "a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (Campbel *et al.*, 2010). Those alien species which have thus increased its spread in the new location displacing the local biota are called as alien invasive species (Keane and Crawley, 2002). Unfortunately, some of the alien species become invasive if they are affecting native biodiversity by competing with other organisms which are referred as Invasive Alien Species (IAS) (Reddy *et al.*, 2008). Invasive plant species is a great risk as they not only change the dynamics of native species composition and biodiversity but also hinder the system productivity and efficiency in invaded regions (Bajwa *et al.*, 2016).

Introduction of the species to the new location can either be accidental or intentional (Van der Putten, 2007). Not all plants introduced from other ecosystem are harmful, but only a small percentage of them having a vigorous reproductive and proliferative potential become invasive. Due to their rapid growth they over pass the native biota in terms of habitat occupation and exploitation of water and nutritional resources. Plant invasions have been recognized as one of the most serious global processes impacting the structure, composition and function of natural and semi-natural ecosystems (Mooney and Hobbs, 2000). The world's worst hundred invasive alien species include microorganisms, macro fungi, plants, amphibians, invertebrates, fishes, reptiles, birds and mammals (Lowe *et al.*, 2000). Several characteristics of the plant species help them to be an invasive and most important among them is the large quantity of seed production and their small size to be carried away to long distances by wind and water (Enserink, 1999). These seeds would have a long gestation period and their sheer number increases the propagule pressure on the new habitat (Carlton, 1996). Further, many alien invasive species are early colonizers which can thrive on resource poor habitats (Funk and Vitousek 2007). With extremely fast establishment and fast growth rates (Burns,

2006) they can make use of tree fall gaps (David Gorchov *et al.*, 2005), degraded forests and forest fringes better than the native species (Rojas *et al.*, 2011).

The phenotypic plasticity exhibited by these plants help them to adapt to a variety of habitats. Homogenizing the world's fauna and flora is the dangerous characteristics shown by the Invasive alien species on its way of extension across the world (Mooney and Hobbs, 2000). The invasion of alien species is a mode of biological pollution and it can act as one of the main causes for species extinction (Drake *et al.,* 2016). The impact of alien invasive species is by way of direct displacement of native plant species. This happens through change of soil chemical profile, rewarding pollinators better than the native species thereby reducing the reproductive success of native species, changing hydrological regimes, making the new habitats fire prone, limiting the photosynthetic efficiency of the native species by reducing light availability. Invasive alien plant species changes the structure of the soil by affecting the rate of decomposition, soil profile, nutrient content and moisture availability are also affected (Lodge *et al.,* 2006). These Invasive alien plant species replace native species through competition for resources like space, nutrients, water and light (Vila and Weiner, 2004). Numerous studies around the world connected with the invasion of alien plant species on forest ecosystems suggest that, these invasions induce structural transformations and make changes in the biogeochemical cycles (Knapp and Canham, 2000).

Wayanad wild life sanctuary which is situated at the junction of three biologically rich and distinct regions viz. The Western Ghats, Nilgiri hills and the Deccan plateau. The core zone of the sanctuary has an area of 111 km^2 and a buffer zone of 233 km^2. Tholpetty range which extend towards north of the sanctuary is off 77.66 km^2 and shares boundary with Nagarhole tiger reserve (Wayanad Wildlife Sanctuary Management plan, 2012-2022). Due to its geographic location, Wayanad wildlife Sanctuary faces considerable anthropogenic pressure but still harbor rich biodiversity and wild animal population. Biological invasion has seriously affected this protected area in the form of weed plant species like *Lantana camara, Chromolaena odorata* and *Senna spectabilis* natives of Tropical America, which now invades most parts of the sanctuary by altering the native plant species compositions.

Lantana became the dominant understory vegetation and it competes with native pastures, interferes with the foraging behavior of cattle, and also causes death due to poisoning (Babu *et al.*, 2009). *Chromolaena odorata* meanwhile has become one of the worst invasive plant in tropics (Waterhouse, 2003). *Senna spectabilis* was reported as world's one of the "handsomest ornamental" by Irwin and Barneby (1982) which was introduced to botanical gardens in India as an ornamental. It escaped from the forest areas of Sikkim and widely became invasive in southern India (Adhikari *et al.*, 2015). Till now *S. spectabilis* is not recorded in the Global Invasive Species Database (2018) even though it is now threatening several ecosystems including Wayanad WLS seriously than any other Invasive alien plant species.

The distribution characters of weeds have been studied but the impacts on natural vegetation is not much emphasized. A study is being conducted in the WS II region constituting three Ranges (Muthanga, Kurichiat and Sulthan bathery) of Wayanad Wildlife Sanctuary in 2017 regarding the impacts of IAPS viz. *L. camara*, *S. spectabilis* and *C. odorata* on native plant species diversity. The study revealed that the serious impact of IAPS on native vegetation as it reduced its diversity drastically. The study also found that *S. spectabilis* as the most potential IAPS that could regenerate swiftly and destruct the native ecosystems. The aggressive behaviour of these IAPS viz. *L. camara* , *S. spectabilis* and *C. odorata* has been reported to alter the plant species composition and is even observed to replace the native species. Hence the current study was framed with the objective to characterize the distribution of these three invasive alien plant species in Tholpetty Range (WS I) which is adjacent to WS II of Wayanad WLS and also to evaluate their impact on native vegetation and to bring out the complete data on impact considering the Wayanad Wildlife Sanctuary.

The specific objectives of the study are;

1. To evaluate the distribution characteristics of selected invasive alien species viz. *Lantana camara* L., *Senna spectabilis* (DC.) H.S. Irwin and R.C. Barneby and *Chromolaena odorata* (L.) R.M. King & H. Rob. in the selected ecosystems inside the Tholpetty of Wayanad Wildlife Sanctuary.
2. To understand the impact of these invasive alien species on the regeneration of other plant communities.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

2.1 INVASIVE PLANT SPECIES

The Earth's flora is dynamic and has been constantly changing over a period of time. Changes may be natural or human-aided, although in the recent past the latter has played a vital role. In fact, the movement of plants from one part of the earth to the other has become very common and frequent owing to better trade and transport facilities (Kholi *et al*., 2012). International Trade, Travel, and Transport - the 3Ts' are the major drivers of biological invasion (McNeely *et al.,* 2001). Plant species that move from one geographical region to the other (either accidentally or intentionally), establish and proliferate there and threaten native ecosystems, habitats and species are known as invasive alien plants (Richardson *et al.,* 2000). Vitousek *et al.* (1997) states that the problem of invasive plants has become global and is predominantly human-aided. Invasive plants are responsible for global environmental changes, the biodiversity crisis, species endangerment, and disruption of ecosystem processes essential for human welfare (Mack *et al*., 2000; Mooney, 2005; Charles and Dukes, 2008; Pejchar and Mooney, 2009).

The impact of invasive plants on global biodiversity is second only to habitat fragmentation and is a major global issue. According to Pimentel *et al.* (2000) The phenotypic plasticity exhibited by these plants helps them to adapt to a variety of habitats and destructs the ecosystem. Furthermore, the economic costs due to invasive species are also enormous, though not widely studied (Pimentel *et al.,* 2005). Invasive species cause extensive effects on the habitats they invade, like impact on indigenous species diversity, soil nutrient composition, altering forest fire cycles and loss of productivity of invading ecosystems (Dogra *et al*., 2010).

It also becomes a threat to endangered or threatened plant species around the world (Pimentel *et al*., 2005). It is supposed that 10% of plant species, on an average, from any region are good colonizers. Thus, it can be estimated that from 260,000 vascular plant species known around the world, only 10% are potential invaders. Further, there are about 10,000 recognized invasives and 40% of these have been interchanged among different regions of the world (Raimundo, 2007). It is also estimated that 20% or more of the plant species are exotics in many continental areas and 50% or more on many islands (Rejmanek and Randall, 1994). Studies of past introductions demonstrate that the effects of invasive species are complex and can permanently alter the structure of communities (Holway *et al.*, 2002; Carlton, 2003).

Environmental problems such as climate change, disturbances and changing landscape patterns have further escalated the process of biotic invasion (Bhatt *et al.*, 2011). The harms caused by biotic invasions are enormous as they interfere with the socio-economic system, human and animal health and food security of the region. Various international and national organizations, such as World Conservation Union (WCU, formerly IUCN - International Union for Conservation of Nature and Natural Resources), Convention on Biological Diversity (CBD) and Global Invasive Species Programme (GISP), are concerned with the prevention and control of this global problem.

2.1.1 Attributes of Invasive Plant Species

Fast growth and reproduction are the major traits of invasive alien plants which often make them spread swiftly in the invaded region. They often attain early maturity and have high regenerative like Parthenium hysterophorus or special organs for vegetative reproduction, such as stolons in *Eichhornia crassipes, Alternanthera philoxeroides* Ageratum conyzoides, root suckers in *Lantana camara,* rhizomes, bulbs in *Oxalis latifolia* or turions. Rooting sometimes may be present at the stem tips like in *Ipomoea carnea* and *Mikania micrantha.* Another important character is a large quantity of seed production and its small size to be carried away to long distances by wind and water (Khare, 1980; Enserink, 1999). Invasive alien plants have an efficient mechanism of dispersal of their seeds or propagules, by virtue of which these spread very rapidly from one place to another.

Potential Competitive advantage on account of allelopathy makes them out pass native plant species. In other words, they release toxic chemicals to the environment that in turn hamper the growth and establishment of native flora. *Parthenium hysterophorus* is a potent allelopathic plant (Kohli and Rani, 1994). *Lantana camara* and *Ageratum conyzoides* are likewise reported as being strongly allelopathic (Ambika *et al.*, 2003; Kohli *et al.*, 2006). In fact, the allelopathic nature of many invasive alien plants forms the basis for the Novel Weapon hypothesis (Heirro and Callaway, 2003).

Absence of natural enemies or predators helps invasive alien plants to greater extents in the new geographical areas to get established as it is devoid of their natural predators or pests that co-evolved with them in their native environment. In the absence of these enemies, their populations grow unchecked and consequently, these form huge monocultures (Heirro and Callaway, 2003).

Ability to adapt to diverse environmental conditions: invasive plants have high ecological amplitude and thus have enormous adaptability to a wide range of environmental conditions. These can survive under stressed conditions and they also have the ability to modify growth patterns in response to changing environments such as soil condition, moisture status or limited space availability.

2.1.2 History of Invasion

Plant movement or introduction to an alien environment is not a new phenomenon but has been an important part of our history. A number of economically important plants such as crops and ornamentals are introduced plants that have proved especially beneficial and non-harmful to the human race (Herron *et al.*, 2007). However, many introduced plant species initially considered to be valuable have become a nuisance and difficult to manage. Example include *Lantana camara*, a South American shrub now known to be a very troublesome invader but now introduced to several parts of the world as an ornamental. There are also examples of accidental entry of some invasive plants as contaminants of imported food grains or agricultural/horticultural material or in ships' ballast water. (Pysek *et al.*, 2012)

Since the 16th century, India experienced a good trade relationship between African, Arabian and Western countries. So many goods were imported and exported to these countries and thereby so many species were accidentally introduced to India. The British, French, Portuguese and Spanish introduced a large number of plants that have been economically important to India. Within India, several exotic plants were introduced intentionally for establishing botanical gardens, arboreta and also for attractive purposes. In 1786, about 3,200 exotic plants were introduced by the East India Company for the establishment of the Royal Botanical Garden (Acharya Jagadish Chandra Bose Indian Botanical Garden) in Calcutta (Kannan, 2013). Among the 3,200 plants, about 992 were introduced from Caribbean and Latin America. As a result, the Garden became a source for growing the alien plant varieties (APS). Some of the introduced plants like *Ipomoea carnea, Lantana camara*, and *Convolvulus arvensis* become invasive in a short time period. Simply by the arrival of globalization, lots of species were dispersed in many countries through air, land, and water. Even though there is a proper quarantine system in many countries, still many alien species were transported across the nations around the world and became invasive in a short time period. Eventually, these species became a huge threat to all ecosystems around the world. An invasive plant such as *Parthenium hysterophorus* - one of the most serious invasive plants is an example of an accidental entry.

2.1.3 Plant Invasions and their type

Plant invasions dramatically affect the distribution, abundance, and reproduction of many native species (Sala *et al.*, 1999). Because of these ecological effects, alien species can also influence the evolution of natives exposed to novel interactions with invaders (Parker *et al.*, 1999). Evolutionary changes in natives in response to selection from aliens are usually overlooked, yet common responses include altered anti-predator defenses, changes in the spectrum of resources and habitats used, and other adaptations that allow native populations to persist in invaded areas (Mooney and Cleland, 2001). So, the introduction of such invasive species leads to change in the structure and composition of native communities (Rice and Emery, 2003).

2.1.3.1 Human introduced invasions

The human-made introductions in the new habitats are quick and responsible for rapid change within the indigenous communities (Ridenour and Callaway, 2001). The introduction of plant species by humans increased during the last five centuries, especially during the twentieth century, due to the rapid increase in trade and travel across the globe. Planes, ships, and other forms of modern transport have allowed both deliberate and inadvertent movement of species, often resulting in unexpected and sometimes disastrous consequences (Moore, 2004). Some times the species are introduced in such environments which can not be chosen by the species themselves for their growth and establishment. The introduction of new species in the balanced ecosystems and habitats can affect the natural process which leads towards destruction or loss of biodiversity (Louda *et al.*, 2003). Introduction of *Eucalyptus citriodora* Hook., *Populus deltoides* Marsh. and *Lantana camara* L. species in India is an example of human-introduced invasions (Kohli *et al.*, 2004; Dogra *et al.*, 2009)

2.1.3.2 Natural invasions

The impact of natural invasion is almost similar to that of human-made invasions but this kind of invasion mostly depends upon the dispersal ability of the invading plants and animals. The time scale for natural invasion can range from a few years to several years. The sources for natural invasion are birds, animals, water and wind, etc (Herbold and Moyle, 1986). *Ageratum conyzoides* L. and *Parthenium hysterophorus* L. are examples of such type of invasions in India (Kohli *et al.,* 2004; Dogra *et al.,* 2009). After a natural invasion by an alien plant species, there is a "lag phase" that may range from decades to centuries before an exponential phase of its fast spread (Ghate, 1991). The species that at a given time may appear to be non-invasive may suddenly begin to spread rapidly. *P. hysterophorus* fits well as an example in this regard. It is reported that the introduction of this species in India occurred accidentally (Bennet *et al.*, 1976) in 1810 and lived in obscurity until Rao reported it in 1956 from Pune. However, its exponential spread was witnessed between 1985 and 1995 when it engulfed almost the whole of India including NW Himalaya (Himachal Pradesh) up to 2000 m (Dogra *et al.*, 2009).

2.1.4 Positive relation between Invasive plants with climate change

Changes in climate can make invasive plants more prevalent and destructive. Liu *et al.* (2017) say that non-native plants, especially invasive species, can thrive on climate change by adjusting the annual activities like flowering and fruiting. Plant invasions have been predicted to further increase under ongoing global environmental change (Funk and Vitousek, 2007). Numerous case studies have compared the performance of invasive and native plant species in response to global environmental change components (i.e. changes in mean levels of precipitation, temperature, atmospheric CO_2 concentration, and nitrogen deposition) (Heberling and Fridley, 2013). Phylogenetically-controlled meta-analysis to assess whether there is a general pattern of differences in invasive and native plant performance under each component of global environmental change (Van Kleunen *et al.*, 2010). It is found that elevated temperature and CO_2 enrichment increased the performance of invasive alien plants more strongly than was the case for native plants. Invasive alien plants tended to also have a slightly stronger positive response to increased Nitrogen deposition and increased precipitation than native plants. So, drought could potentially reduce invasion, increases in the four other components of global environmental change considered, particularly global warming and atmospheric CO_2 enrichment, may further increase the spread of invasive plants in the future (Liu *et al.*, 2017).

Invasive alien plant species outperform native plants in the recipient native communities has become a hot topic in ecology (Heberling and Fridley, 2013). With the ongoing global environmental change, there is also increasing interest in how the spread of invasive plants may change in the future (Dukes and Mooney, 1999; Bradley *et al.*, 2010, Jia *et al.*, 2016).

This is because invasive plants often exhibit broad environmental tolerance and high phenotypic plasticity, which may confer the capacity to survive in altered environmental conditions (Richards *et al.,* 2006; Davidson *et al*., 2011). Furthermore, the intrinsically high growth rate characteristic of many invasive plant species (Grotkopp *et al*., 2010; Van Kleunen *et al.,* 2010; Dawson *et al*., 2011) may enable them to respond more positively to environmental change.

2.2 STATUS AND VULNERABILITY OF THE INDIAN REGION TO PLANT INVASION

The Indian region, because of its diverse climatic and environmental conditions, is highly vulnerable to biotic invasion. Moreover, a burgeoning population, high rate of trade and transport, coupled with the greater movement of people favor the accidental and intentional entry of plant species in this region. India occupies 2. 4% of the total land area of the world and the contribution to the world's total species diversity is 8 %. The described number of species on earth is usually estimated to be just 1. 75 million (Meekins and McCarthy, 2001). India offers extensive trade history with many countries through air, sea, and land and these channels will be the major reasons for the transfer of alien plants and animals from various geographical regions. Nowadays these movements are more rapid and the chance for being a good invasive is higher.

Within India, there are about 45,000 plants species (MoEF Annual report, 2012-13). According to Mandal (2011) 173 species of the Indian flora are invasive alien plants. About 40% of the species in the Indian flora are alien (Raghubanshi *et al*., 2005). 74% of introduced species are native to South America and 11% was from tropical Africa. It is clear that 80% of the IAPS were introduced from neotropics. 151 herbaceous species, 14 shrubs, 5 climbers and 3 trees forms a total list of 173 IAPS (Mandal, 2011). Sankaran and Suresh (2013), has offered a comprehensive data relating to phenology, habitat, damage brought on and management options of invasive plants in the jungles of India.

The Important IAPS which is observed in India include *Ageratum cony- zoides, Eupatorium adenophorum, Eupatorium odoratum, Lantana camara, Mikania micrantha , Chromolaena odorata, Ageratum conyzoides, Mimosa diplotricha var. diplotricha, Acacia mearnsii, Agertainaa denophora, Cuscutareflexa, Arundodonax, Leucaena leucocephala, Prosopis juliflora Parthenium hysterophorus* have caused havoc in terrestrial ecosystems, and *Eichhornia crassipes*, Ipomoea spp. and *Salvinia molesta* in aquatic ecosystems (Sankaran and Suresh, 2013). A study conducted on the diversity of Invasive alien plant species by Chandrasekar (2012) reveals about a total of 190 invasive alien species under 112 genera, belonging to 47 families. Among these, the dicotyledons represent by 40 families, 95 genera and 170 species; mono- cotyledons represent by 7 families, 17 genera and 20 species. The analysis of invasive species reveals that 18 species have been introduced intentionally, while the remaining species established unintentionally through trade. In terms of the nativity, amongst 13 geographic regions, the majority of invasive plants reported from the American continent (73%). While in life form analysis, the herbs (148 species) are dominant, followed by shrubs (19 species), Grass (11 species). Nearly 60% of India's bio-wealth is contributed by fungi and insects (Khoshoo, 1996). As a mega diversity country, India harbors 45,000 wild plant species and about 90,000 animal species in less than 50% geographical region surveyed so far (MoEF, 2008). In India, 18,000 plant species, 30 mammal species, 4 bird species, and over 300 fish species are alien (Pimentel *et al.*, 2005). About 40% of the Indian flora is alien, of which 25% are IAS (Raghubanshi *et al.*, 2005).

2.2.1 Kerala scenario

The study conducted by Sajeev *et al.* (2012) identified 38 alien invasive species in the forests of Kerala, of them, 10 are of high risk, 12 pose a medium risk, 10 pose a low risk and 6 insignificant as per the risk assessment conducted. There are 5 trees, 11 shrubs, 4 subshrubs, 12 herbs and 6 climbers among the alien invasives found in the forests of Kerala. The land of origin of the alien invasives happens to be America for 11 species, South America for 10 species, Central

America for 6 species, Central and South America for 4 species, and Asia for 3 species. One each of the alien invasives is from Africa, Australia, West, and Central Africa, and the West Indies. Most of the introductions into the forests of Kerala was intentional (31 species).

A study conducted by KFRI in 2012 identified 38 IAPS in the forests of Kerala. Using the Invasive Species Assessment Protocol (Morse *et al.,* 2004) these species were grouped to various risk categories. Among that 10 are possessing high risk viz. *Acacia mearnsii, Lantana camara, Chromolaena odorata, Merremia vitifolia, Mimosa diplotricha var. diplotricha, Mikania micrantha, Mucuna bracteata, Prosopis juliflora, Pueraria phaseoloides and Sphagneticola trilobata.* Twelve were medium risk species, 10 having lower risk and data for 6 are insignificant (Sajeev *et al.,* 2012). Out of 38 introduced species, 11 were from America and 14 species was introduced from South America. Central America was the native of 6 species. Only 3 species were from Asia and rests of them were from Africa, Australia, and West Indies. Among the 38 species, 31 were introduced intentionally to the forests of Kerala.

2.3 ECONOMIC LOSS

L. camara is toxic to cattle and cost towards its control was US$70 per hectare (Singh *et al.,* 1996). The economic loss from *Lantana* is estimated to be US$924 million per year. Invading alien species in the United States cause major environmental damages and losses adding up to almost $120 billion per year. There are approximately 50,000 foreign species and the number is increasing. About 42% of the species on the Threatened or Endangered species lists are at risk primarily because of alien-invasive species. Based on a case study conducted in the Philippines, there was a loss of 70,000 – 100,000 tons of paddy in the production sector due to the IAPS in 1990. The IAS makes an economic loss of US$ 400 billion across the world every year (Pimentel *et al.,* 2000). The total economic losses caused by invasive alien species to China were to the time of USD 14.45 billion, with direct and indirect economic losses accounting for 16.59% and 83.41% of total economic losses, respectively (Xu *et al.*, 2006). The estimated annual economic damage from invasive alien species (IAS) worldwide totals more than the US $1.4 trillion per annum close to 5 % of GDP. Annual economic losses due to IAS in various countries have been estimated to be about the US $30 billion in USA, €12 billion in Europe, £1.7 billion in Great Britain (GB Non-native species Secretariat), 14 billion US $ in China. In view of these ecological and economic impacts of IAS, parties to the convention on biological diversity, in 2010 in Nagoya, Japan, adopted the strategic plan for biodiversity 2011–2020 in which the Target 9 under the Strategic Goal B stipulates that by 2020, IAS and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

2.4 IMPACTS ON BIODIVERSITY

The invasion of ecosystems by alien species has been identified as a large and growing threat to the delivery of ecosystem services (Drake *et al.*, 2016). Biodiversity is needed for ecosystems to function effectively, and thus to deliver services (de Groot *et al.*, 2007). An Invasive alien species refers to an alien species whose introduction and/or spread threaten biological diversity of the region/habitat (CBD, 2002). Recently, these Invasive Alien Species (IAS) have been emerging as the second biggest threat to global biodiversity after habitat destruction and it is expected to soon surpass the damage caused by habit destruction and fragmentation (De Milliano *et al.*, 2010; Zhang and Chen, 2011; Surendra *et al.*, 2013).

A key driver of change in ecosystems are the invasions by alien species, many of which attain sufficiently high abundance to influence biodiversity miserably (Tylianakis *et al.*, 2008). It has also been reported that Invasive Alien Species may cause changes in environmental services, such as flood control, water supply/level, water assimilation, nutrient recycling, conservation and regeneration of soils (Armstrong, 1995; GISP, 2004). They even replace desired native plants and prevent the native plants from establishing because of their superior competitive ability (Buchanan, 2000). For example, in California and Arizona, perennial native and palatable plants lost competitiveness and invasive plants have become dominant (Bridges, 1992). Diffuse knapweed is an example of an invasive plant that prevents the growth of native species (Fletcher and Renney, 1963; Muir and Majak, 1983).

2.4.1 ***Chromolaena odorata* (L.) R. M. King and H. Robinson**

Chromolaena odorata, a neotropical Asteraceae commonly known as Siam weed, introduced to many parts of the tropics is considered to be one of the most aggressive invasive plants in tropical and sub-tropical areas (McFadyen, 1991; Witkowski and Wilson, 2001). *Chromolaena odorata* is a native plant from Florida to the West Indies and from Texas through Central America and through South America to Argentina (Howard, 1989; Liogier, 1997). It is found accidentally or is deliberately introduced. It is reportedly one of the world's most invasive weeds and is a serious weed in central and western Africa, India, Australia, the Pacific Islands, and Southeast Asia (McFadyen, 2003). This species has a wide tolerance to various climates and has invaded five continents (Kriticos *et al*., 2005). It can become quickly established and smother plant crops, forestry, and native vegetation (McFadyen and Skarratt, 1996). It is unpalatable and noxious and may cause death if domesticated animals ingest it (Aterrado and Bachiller, 2002).

In the year1845 it was introduced as an ornamental plant to Calcutta. The invasion to the Western parts of India mostly in the States West Bengal and Orissa was high during the World War (1924-25). Raghubanshi (2005) says that it was from here this plant was spread to Kerala during 1942 and become invasive in southern India. *Chromolaena* spread swiftly to Southeast Asia, Western Pacific, Africa and northern Australia (Muniappan *et al*., 2002). High allelopathic properties help it to suppresses the neighboring vegetation. During dry seasons most of the stems will be dried, sometimes it will burn and is potential fuel for a forest fire. This species is becoming a serious problem in plantation crops, especially in teak, and it is also becoming a problem in disturbed forests. Stumps are generally unaffected by the fire, and by the rainy season rapid growth is shown and they spread into all other areas within a short time.

2.4.1.1 Global impact of Chromolaena

Ramalevha *et al.* (2018) has studied the impact of *Chromolaena odorata* on native species in Vhembe District, of South Africa. No new native species were identified from the study area. The *Chromolaena* cover showed an inverse relationship with the canopy cover and height of native plants.

Orapa *et al.* (2002) studied the distribution and impact of *Chromolaena* in Papua New Guinea. Reforestation programs in Kimbe region were severely affected by *Chromolaena*. Some poorly managed pasture lands and village home gardens were also affected. In these areas, the weed was particularly robust and impedes access to and cultivation of food gardens. Open hill lands were completely affected by *Chromolaena*. During the dry season, these thickets dried and become fire risk to the adjacent rainforests.

The impact of *Chromolaena* in South Africa was studied by Zachariades *et al.* (2004). *Chromolaena* formed higher plant biomass than the native vegetation in the forest area. Through allelopathy and physical smothering, this weed suppressed the native grasslands and savanna vegetation. The forest biodiversity in the study area was severely affected by *Chromolaena*. It was recorded in the commercial forestry sector that the growth of young eucalyptus and pine trees were suppressed through competition. A decrease of 7% in water run-off was also observed due to alien vegetation.

C. odorata is a rapidly growing perennial shrub native to the tropical and subtropical Americas, found in many places from southern Florida to the extreme north of Argentina (Barreto & Evans, 1994). It is now a widespread and dominant agricultural weed in many countries across western and southern Africa, Australia, and tropical east and south Asia, forming dense shrub thickets in monoculture and shading out other vegetation (Mgobozi *et al.*, 2008; Okon *et al.*, 2013). Raimundo *et al.* (2007) also noted the ongoing spread and predicted the further spread of *C. odorata* northward from South Africa, eastward from West Africa and into Australia from the Pacific Islands. It is listed as one of the world's worst invaders (Lowe *et al.*, 2000) and is reported to be the second most invasive plant in South Africa (Robertson *et al.*, 2003). *C. odorata* spreads by wind and attachment to fur and clothing and can travel long distances (Hauser and Mekoa, 2009). This plant is so problematic that it became the sole focus of eight international workshops organized by the International Organization on Biological Control (IOBC) between 1988 and 2010. The distribution and habitats of *C. odorata* and *A. adenophora* are somewhat different. *A. adenophora* is more subtropical and is found in cooler sites at somewhat higher altitudes, as well as being shade tolerant, while *C. odorata* is a high light-demanding species that tend to grow in warmer sites than *A. adenophora*.

2.4.1.2 Impact of Chromolaena in India

A study on distribution and impact of *Chromolaena* was conducted by Sutari *et al.* (2016) in Kinnerasani Wildlife Sanctuary of Telangana. It was estimated that 70% of infestation was in the buffer zone and 30% in the core zone of the sanctuary. It was found that the seeds of *Chromolaena* stuck on animal skins and are moved with grazing cattle, goat, and also the wild animals. Earlier it was also reported that the seeds of Chromalaena were dispersed by wind, animals, and vehicles (Zachariades *et al.*, 2009). The huge thickets of *Chromolaena* that were formed in the sanctuary hindered the free movement of wild animals. This weed competed with another native plant for nutrients, light, minerals, and water. Thereby it suppressed the growth of surrounding vegetation and affected regeneration. Grazing area of the herbivores is tremendously reduced.

A study conducted on *Chromolaena odorata* on Soil Properties in the Atharamura forest ecosystem by Debnath *et al.* (2018) shows that the impacts of

Chromolaena by damaging the soil physiochemical, microbial and nutrient cycling and *Chromolaena* are necessary to be removed to avoid potential threats to native biodiversity and forest economic losses in this tropical zone.

2.4.1.3 Impact of Chromolaena in Western Ghats

Balaguru *et al.* (2016) studied the effect of *Chromolaena odorata* and *Lantana camara* on native plants in Palani hill National Park (PHNP). About 12,568.3 ha and 2208.11 ha infested by *Lantana* and *Chromolaena* respectively. The results of the study revealed that the impact of *Chromolaena* shows lesser impact than *Lantana* in the PHNP. The species composition, nutrient cycling and the water availability were altered by the invasion. The study reported that the invasive species distribution showed a negative relationship with the species richness of native species. But the invasive species distribution and species dominance showed a positive relationship. The forest types in NP viz. moist deciduous, dry evergreen and tree savanna were vulnerable to *Lantana* and *Chromolaena* invasion. They observed that the invasive species are abundantly seen in the dry mixed deciduous forest. The trees in this forest type have only less basal area and crown cover which increased the light intensity supports the weed growth. These provided a suitable environment for the growth and spread of *Chromolaena*.

2.4.2 *Lantana camara L.*

Lantana is a member of the family Verbenaceae and is a pantropical weed affecting pastures and native forests in more than 60 countries worldwide (Parsons and Cuthbertson, 2001). It is also known as Spanish Flag and considered as one among the top 100 invasive species and it is one of the top 10 worst weeds of the world. It occurs in diverse habitats and on a variety of soil types. The plant generally grows best in open, unshaded situations, such as degraded land, pasture, edges of tropical and subtropical forests, warm temperate forests, beach fronts and forests recovering from fire or logging

Being beautiful flowers, they are introduced to East India Botanical Gardens in Calcutta by the British in 1807 (Ramesh *et al.,* 2017). It paved the way for challenges to the foresters and farmers. it was spread to all parts of the country within a short period About 650 varieties of *L. camara* are in the world today (Kohli *et al.,* 2006).

The main reason behind the invasion of *Lantana* in forest lands are the presence of a large number of pollinators. They produce a large number of seeds and they are get dispersed successfully by agents like birds, rodents, foxes and other vertebrate forages. Thus, dispersed seeds are highly adaptive to all extreme climatic conditions.

Lantana cannot survive under dense and intact canopies of taller native forest species and it is susceptible to frosts, low temperature and saline soils. This plant tends to rot in boggy or hydromorphic soils and is sensitive to aridity (Van Oosterhout *et al.,* 2004).

Allelopathic character is shown by most of the varieties of *Lantana* in nature, the chemicals released by the roots hinders the growth of nearby plants (Sharma *et al.,* 2005).

2.4.2.1 Global impact of Lantana

In Australia, the plant was first reported in 1841 and 1897, it was recognized as one of the most troublesome weeds (Van Oosterhout *et al.*, 2004). It is now spreading to form impenetrable thickets on the edges of forest and covers 4 x 106 ha across Australia and the study found that when there was a low abundance of the *Lantana*, their impact on native species is very little. But when the abundance of *Lantana* increased above a threshold level, the native communities decline rapidly. (Van Oosterhout *et al.*, 2004). Globally, it infests millions of hectares of grazing land and is of serious concern in 14 major crops including coffee, tea, rice, cotton, and sugarcane. Disturbed areas, such as roadsides, railway tracks, and canals, are also favorable for the species (Munir, 1996). It does not appear to have an upper temperature or rainfall limit and is often found in tropical areas receiving 3000 mm of rainfall per year. *Lantana* seldom occurs where temperatures frequently fall to <5°C (Cilliers, 1983).

The species richness of native plants was compared with the cover of *Lantana* which showed a strong negative non-linear relationship. The species richness of native species remained stable below 75% *Lantana* cover. But above the threshold level, the species richness declined rapidly. This leads to compositional change. The study concluded that at low rates of *Lantana* infestations, there was only little impact on the indigenous species. But the impact increased rapidly at the further invasion of *Lantana*.

2.4.2.2 Impact of Lantana camara in India

Studies conducted in the southern part of India about the tropical dry forests reveals that the *Lantana* thickets alter the plant community composition. It also affects the establishment of native seedlings (Ramaswami and Sukumar 2014; Prasad, 2010).

A study conducted a study on Ecological audit of invasive weed *Lantana camara* L. along an altitudinal gradient in Pauri Garhwal by Dobhal *et al.* (2010) shows high reproductive ability, absence of natural predators and sufficient moisture availability provided by the nearby water source were the factors which favored the extraordinary growth of *Lantana* in the study area. There were reduction in productivity of herbs and fodder grasses due to *Lantana* invasion in the forest areas.

Sharma and Raghubanshi (2006) studied the change in regeneration status of tree species at various levels of *Lantana* invasion. The study was conducted in Vindhyan plateau of Uttar Pradesh and the diversity of the plateau improved with reduction of *Lantana* cover. About 26 species and 6825 individual seedlings were obtained at low *Lantana* invasion area. There are only 17 species and 2925 seedling at high *Lantana* cover areas. There is only little regeneration in high *Lantana* cover areas. Species like *Briedelia retusa, Anogeissus latifolia, Emblica officinalis, Casearia elliptica, Hollarhena antidysenterica, Flacourtia indica, Semecarpus anacardium, Schrebera swietenioides* showed better regeneration in highly invaded areas.

During the study it was found there was a huge loss of species diversity and species richness of native species in invaded areas. There was a decrease of species richness by 28.4% in the invaded localities. On comparing the loss of vegetation basal areas in *Lantana* invaded and non-invaded regions, there was a loss of 63%. The study concluded that in the riparian forest, *Lantana* favored exotics than endemic species.

The *Lantana* invasion reduced the biomass and density in the forest area of India (Kohli *et al.*, 2006). Native herbs and shrubs in the forest understorey are being replaced by the weed and became dominant. *Lantana* makes difficult in forest operations by its sprawling growth habit. *Lantana* invasion reduced the fodder cover in pastures and grasslands. These changed the foraging behavior of cattle and wild herbivore's browsing area is reduced. In India, chances for spreading sandal spike disease was common in *Lantana* affected sandalwood forests which affects the quality of timber.

In different ecosystems of the Indian subcontinent, it was noted that the number of species was much lesser in *Chromolaena* affected plots and the regeneration of native species was seriously affected but *Lantana* shows comparatively less impact on the regeneration of the native species (Murali and Setty, 2001)

2.4.2.3 Impact of Lantana camara in Western Ghats

A study conducted on the impact of *Lantana* on vegetation in Mudhumalai Tiger Reserve (TR) of Tamilnadu by Kumar *et al.* (2012) Similar to a work conducted in Africa by Totland *et al.* (2005) states that the human interference and canopy openness increased the *Lantana* invasion. The changes in elevation also affected the weed invasion in the TR. They reported that maximum grass availability was obtained in the weed-free areas (54%) and only 19% of grass was present in weed affected area. Species richness of grass species showed an inverse relationship with the density of *Lantana*. This adversely affects the foraging behavior of herbivores and eventually affect the balance between flora and fauna. A study shows that the vegetation types in Mudumalai Tiger Reserve provide a good foraging area for vultures. Invasive alien species such as *Lantana camara* makes them find the carcass difficult and disturbs their food necessities (Samson *et al.*, 2016).

Velliangiri Hills is a region in southern parts of Western Ghats were cleared for agriculture and timber extraction. The study conducted by Aravindhan and Rajendran (2014) found that the cleared forest area enhanced the invasion of exotic species. These became perfect corridors for seed dispersal and provides suitable habitat for *Lantana*. Only little species viz. *Sida acuta, Oxalis corniculata, Cyanotis cristata, Leucas aspera, Dioscorea belophylla, Triumfetta rhomboids and Evolvulus alsinoides* were seen along with abundant *Lantana* infected areas.

The fire history with the distribution of *Lantana camara* in the tropical dry forests of TR was studied by Ramaswami and Sukumar (2014). A high density of *Lantana* was seen in regions which were affected by fire once. Some areas in the Mudumalai TR were affected by continuous fire, about 11 times in the year 1989-2010 was fire affected. These regions showed only less infestation of *Lantana*. It was noticed during the study that, *Lantana* invasion was greater under medium shade conditions (40–70% open) (Ramaswami and Sukumar, 2014). They also noticed that the *Lantana* invasion becomes severe when there is more availability of light at ground level (Raizada *et al.*, 2008).

2.4.3 *S. spectabilis* (dc.) Irwin & Barneby

S. spectabilis is a taxonomically diverse and widespread genus. The term *S. spectabilis* was derived from an Arabic word which means that the species has laxative and cathartic properties. There are about 300 species in the genus *S.*

spectabilis. The origin of *S. spectabilis* tree is America. The first report of this tree was from Sathyamangalam forest and Wayanad Wildlife Sanctuary (WLS) in Kerala (Satyanarayana and Gnanasekaran, 2013). This species was introduced to India as an ornamental plant. Later it escaped from cultivation and reported in the forest areas of Mysore and Sikkim. In Wayanad WLS this species shows tremendous growth and produce a large number of seedlings. Now it has become an IPS in the forest areas and makes a huge impact on the native species.

2.4.3.1 *Global impact of S. spectabilis*

In Tanzania a study was conducted for the control of *S. spectabilis* by Wakibara and Mnaya (2002). During the study, it was noted that the growth of indigenous trees was suppressed by *S. spectabilis*. It was found that there was only little tree diversity in *S. spectabilis* dominated sites. This *S. spectabilis* has high allelopathic nature and suppresses the growth of neighboring native species except for maize and rice. In the study area, there were about 586 trees of *S. spectabilis* in one hectare, while there were only 1-43 native trees. In disturbed natural forests *S. spectabilis* competes aggressively and this was not seen in closed-canopy areas. The *S. spectabilis* trees which were managed by girdling methods showed better regeneration of native plants.

Mungatana and Ahimbisibwe (2010) studied the impact of *S. spectabilis* in the forest of Uganda. The *S. spectabilis* trees were good breeding habitats for mosquitoes which transmitted malaria. During the study, it was understood that the *S. spectabilis* invasion has adverse effects on environmental services such as cropping systems, livestock grazing, and recreational uses. Further, it was noted that these were the primary cause of ecosystem decline and biodiversity loss. Findings of this study indicated that vast forest areas were severely affected by *S. spectabilis* which declined the productivity and normal functioning of the forest.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The current research "Impact of invasive alien plants (IAP) on understorey vegetation in Tholpetty Range of Wayanad Wildlife Sanctuary" was performed to evaluate the distribution characteristics of selected invasive alien species viz. *Lantana camara* L., *Senna spectabilis* (DC.) H.S. Irwin and R.C. Barneby and *Chromolaena odorata* (L.) R.M. King & H. Rob. in the selected ecosystems inside the Wayanad Wildlife Sanctuary (WWLS). Understanding the impact of these invasive alien species on the regeneration of other plant communities was the major thrust area of this study. Additional work was done to know the effect of crown openness in the growth of the above-mentioned invasive alien plant species.

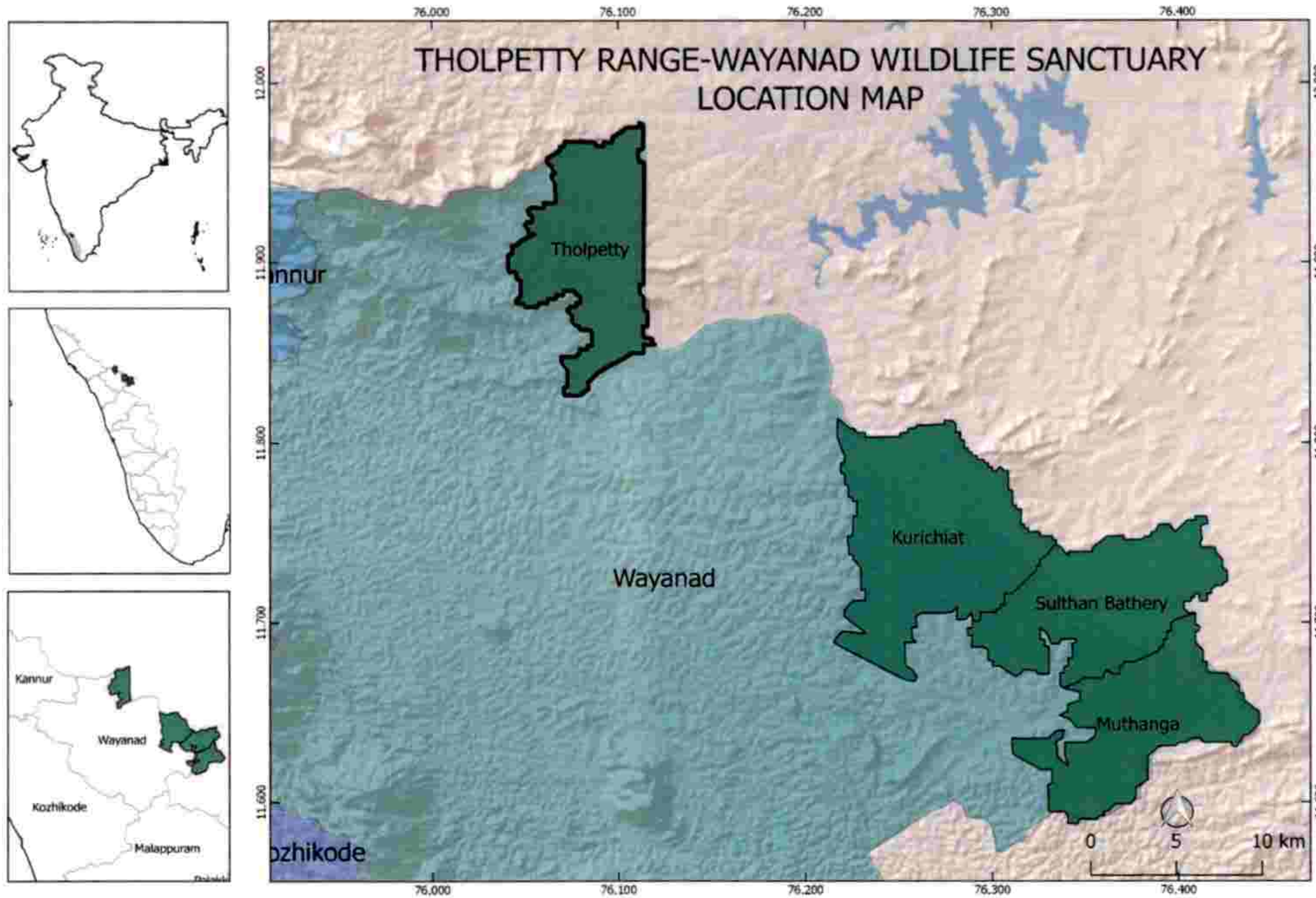
3.1 LOCATION

The study area, Tholpetty Range, lies in the northwest side of the main portion constituted by Kurichiat, Sulthan Bathery and Muthanga Ranges of Waynad wildlife sanctuary. Tholpetty range with its combination of natural forests, swamps and large area of plantations provides a comparative study on impact of invasive alien plant species and its impacts. Moist deciduous are the predominant forest type found here and are widely stretched towards the west and south of Begur RF of Tholpetty Range. Bavali Dasankatta , Kaimaram and Thirulkunnu are the four sections of Tholpetty Range and spread over 7767 Sqkm (GOK, 2016). Tholpetty is an important part of Wayanad wildlife sanctuary having high ecological significance. This Range shares its major part of its boundary with Nagarhole tiger reserve of Karnataka.

Being part of Wayanad wildlife sanctuary actually makes Tholpetty one of the key area for this research. Wayanad is the district of Kerala which has an area of 2132 km^2 known as the land of paddy fields. Its location lies between an altitude of 700 to 1200 m above mean sea level. The forest cover is about 37% of the total area. (GOK, 2016). Wayanad Wildlife Sanctuary (WWLS) has an area of 344 km^2. It constitutes two discontinuous portions of 77.67 km^2 (WS-I) and 266.77 km^2 (WS-II).

Wayanad is situated at the junction of three biologically rich and distinct regions viz. The Western Ghats, Nilgiri hills and the Deccan plateau. The sanctuary shares its boundary with Nagarhole and Bandipur Tiger Reserves of Karnataka in the northeastern side and in southeast, it is Mudumalai Tiger Reserve of Tamil Nadu. These four adjoining PAs constitute about an area of 2,184 km^2 and provide a geographical and ecological contiguity. The core zone of the sanctuary has an area of 111 km^2 and a buffer zone of 233 km^2 (Wayanad Wildlife Sanctuary Management Plan, 2012-2022). It is the 7^{th} elephant reserve having world's largest Asian Elephants population. The whole forest area is under the catchment of Kabani River and its tributaries. During the 1900's a major portion of the natural forest in the sanctuary was converted to teak plantations. Later in 1973 the forest area was declared as sanctuary, and the clear felling and regeneration of plantations were stopped. Then, these plantations were managed as part of habitat restoration, for their gradual transformation into diverse forest habitat.

In Tholpetty the reports on forest fire incidence is almost nill which states about the low risk on forest fire related impacts. Majority areas inside the teak plantation, there was no natural regeneration except some of the interior teak plantations inside Tholpetty range. Three rare nesting places of vultures have also been located in the Sanctuary. One of the nesting places is at Doddady in Tholpetty Range.



(Source: WWLS Management plan)

Figure 1. Location map of the study area

3.2 CLIMATE

Maximum rainfall is obtained during the southwest monsoon. The sanctuary has a mean annual rainfall of 1787.90 mm. Number of rainy days in a year varied from 97 to 174 with mean figure of 143 over last 10 years. The monthly temperature ranges from 31.2°C to 15°C. The maximum and minimum RH in the last 10 years was 93.6% and 42.9% respectively (GOK, 2012).

3.3 VEGETATION

Based on the classification of forest types of India which was revised by Chandra Sekharan (1962) and Champion and Seth (1968), two forest types are seen in Wayanad WLS. They are (a) 3B/C2 South Indian moist mixed deciduous forests and (b) 5A/C3 Southern dry mixed deciduous forests.

3.3.1 3B/C2 South Indian moist mixed deciduous forests

The main characters of this forest type are a leafless period in the dry season and sometimes it may begin with cold weather. During February to April the upper canopy remains leafless. This is the most commonly seen forest type in the sanctuary. These moist deciduous forests are found evenly distributed in all areas of WS I and mostly found in Begur RF and Tholpetty (RF). Considering the west and south of Rampur Reserve (Sulthan Bathery Range), south and west of Mavinahalla RF (Muthanga Range) and most of Kurichiat RF (Kurichiat Range). The common trees seen in this area are *Shorea roxburghii, Terminalia tomentosa, Grewia tiliifolia, Dalbergia latifolia, Terminalia paniculata, Pterocarpus marsupium, Alstonia scholaris, Kydia calycina, Careya arborea* etc.

3.3.2 5A/C3 Southern dry mixed deciduous forests

These forests are seen along the interstate forest boundaries in Begur RF and Mavinahalla RF. Leaf fall is common even in the month of December and it extends to pre-monsoon. The commonly seen tree species are *Shorea roxburghii, Anogeissus latifolia, Terminalia alata, Terminalia chebula, Pterocarpus marsupium, Gmelina arborea, Schrebera sweitenioides, Diospyros montana, Grewia tiliifolia, Dalbergia latifolia, Mitragyna parvifolia, Bauhinia racemosa, Xeromphis uliginosa* and *Tectona grandis*.

3.3.3 The bamboo brakes

The dominant bamboo species seen in the sanctuary is *Bamboosa bamboo. Dendrocalamus strictus* is also seen in some parts. Bamboo brakes are seen in Ponkuzhy area in Mavinahalla and Rampur RF, Dasankatta and begur RF of Tholpetty range.

3.3.4 Swamps/*Vayal* (low lying grasslands)

Swamps in the sanctuary are the edaphic climax. The main characteristic of the swamps is that, they have deep clayey soils and they will be waterlogged in the rainy season. An area of 715.79 ha is under *Vayal* inside the sanctuary. They are commonly known as '*Vayal*s' as they sustain grasses throughout the year. Because of waterlogged condition there are only little trees in *Vayal*s. These open grasslands are the main sites of herbivores foraging. Many of the *Vayal*s are given for lease to the farmers as part of Grow More Food Campaign. Both tribal and nontribal are doing cultivation in these *Vayal*s.

Table 1. Number of *Vayal* (swamps/low lying grassland)

Sl.no	Range	No. of *Vayals*	Extent (Ha)
1	Muthanga	29	189.79
2	Sulthan Bathery	20	147.00
3	Kurichiat	32	217.00
4	Tholpetty	33	162.00
	Total	114	715.79

(Source: GOK, 2012)

3.3.5 Plantation

Teak and eucalyptus plantations occupy about 7,495 ha and 425 ha respectively in the sanctuary (Table 2). There are Teak plantations of the year 1977, 78, 79, 81, 82. After the declaration of the sanctuary the clear felling and regeneration of plantations were stopped. Then, these plantations were managed as part of habitat restoration, for their gradual transformation into diverse forest habitat.

3.4 STUDY LOCATION

The study was conducted in the Northern portion of the Sanctuary (WS-I). It constitutes three forest sections, Bavali Dasankatta , Thirulkunnu , Kaimaram. The WS I lie within the geographical range of latitudes 11°35' N and longitudes 76°13' E. Table 2. Area of plantation in Wayanad WLS

Table 2. Area of Plantation in Wayanad WLS

Sl.no.	Range	Reserve Forest	Extent (Ha)
1	Muthanga	Edathara RF	1466.897
		Mavinahalla RF	
		Noolpuzha RF	
2	Sulthan Bathery	Alathur RF	1817.305
		Kallur RF	
		Rampur RF	
3	Kurichiat	Kuppady RF	370.045
		Kurichiat RF	
4	Tholpetty	Begur RF	3840.570
		Edkode RF	
		Kartikulam RF	
		Kudrakkode RF	
	Total		**7494.817**

3.5 SAMPLING METHOD

3.5.1 Estimation of weed cover and density

The WS I of sanctuary was divided into three vegetation zones viz. Natural forest (NF), Plantation and Swamps/*Vayal* (low lying grasslands). Through reconnaissance survey, eighty 10 m × 10 m sample plots were randomly selected in each of the three above mentioned vegetation types. The percentage of ground covered by the invasive alien plant species (IAPS) like *Lantana camara, Chromolaena odorata* and *Senna spectabilis* in these 10 m × 10 m sample plots were estimated by measuring the crown area. Assuming the crown as a circle the length of crown spread was measured using a tape. The number of standing stems of these IAPS in these 10 m × 10 m plots were

3.5.2 Estimation of other vegetation characters

All the other tree species (> 10 cm GBH) standing inside the 10 m x 10 m sample plot were identified and their GBH and height is recorded (Fig. 2). All the herbs, shrubs, grasses and trees in the study area were identified using software; Flowering plants of Kerala (KFRI) and India biodiversity portal.

3.5.3 Distribution characteristics of IAPS

The distribution of the three IAPS in WS I was marked using GPS and the abundance was plotted using QGIS.

3.5.4 Regeneration survey

Inside the 10 m × 10 m sample plots, six 2 m × 2 m nested plots were randomly laid out to count the number of other plant forms (including regeneration). The plant forms are identified with the help of experts and by referring standard floras.

3.5.5 Weed category areas

Based on the observation of invasive species infestation, the whole study area was divided into the following seven weed categories.

i. *L. camara* infected areas (L): The plots that have only *L. camara* and other plant species.
ii. *C. odorata* infected area (C): The plots that have only *C. odorata* and other plant species.
iii. *S. spectabilis* infected area (S): The plots that have only *S. spectabilis* and other plant species.
iv. *L. camara* and *C. odorata* infected area (LC): The plots that have *L. camara* and *C. odorata* with other plant species.

v. *L. camara, C. odorata* and *S. spectabilis* infected area (LCS): The plots that have *L. camara, C. odorata* and *S. spectabilis* with other plant species.

vi. *C. odorata* and *S. spectabilis* infected area (CS): The plots that have *C. odorata* and *S. spectabilis* with other plant species.

vii. Weed free areas (Control): The plots which do not have any of these selected IAPS associated with other vegetation character.

3.6 ANALYSIS

3.6.1 Phytosociological analysis

Phytosociological analysis was conducted as given below:

$$\text{Density (D)} = \frac{\text{Number of individuals}}{\text{Hectare}}$$

$$\text{Relative Density (RD)} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Abundance (A)} = \frac{\text{Total number of individuals of a species in all quadrats}}{\text{Number of quadrats of occurrence of the species}}$$

$$\text{Frequency (F)} = \frac{\text{Number of quadrats of occurrence of the species}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Relative frequency (RF)} = \frac{\text{Frequency of individual species}}{\text{Sum of frequency of all species}} \times 100$$

Species richness was calculated according to Margalef (1958). Diversity was calculated using Simpson's index (Simpson, 1949). The evenness was calculated in terms of Pielou's Equitability Index (Pielou, 1969). Dominance was calculated using Berger-Parker Dominance Index (Berger and Parker, 1970).

a) Simpson Diversity Index $= \frac{\sum_i n_i (n_i-1)}{N(n-1)}$

b) Berger-Parker Dominance Index $= \sum_i [(\frac{ni}{N} \log_2(\frac{ni}{N})]$

48

c) Margalef Richness Index $= \sum_i[(\frac{ni}{N}\log_{10}(\frac{ni}{N})]$

d) Pilou's Equitability Index $= \frac{\sum_i[\frac{ni}{N}\ln(\frac{ni}{N})]}{N}$

n_i - Number of individuals of the species

N – Total number of individuals

3.6.2 Estimation of crown openness using Spherical Crown Densiometer

Spherical Crown Densiometer, is useful when establishing spacing standards in forest thinning and determining light requirements for regeneration. Convex model A of brand Forestry Suppliers was used to conduct the study regarding canopy openness (Plate 1). The data collected has used to study the correlation with the percentage cover of IAPS in WS I region. Model features a mirror reflector engraved with a cross-shaped grid of 24 quarter-inch squares to delineate a plot overhead (Plate 1). Walnut instrument case is 3" x 3" with built-in leveling bubble. Slightly offset convex model when using so head won't appear on the grid (Plate 2). Assessment of value is done by counting the shades falling over the grids and calculation was done using correction factor (1.04).

3.6.3 Statistical analysis

The variations in the species richness of native species among the three-vegetation type and seven weed category areas were investigated using Two Way Analysis of Variance with interaction. Multiple regression equation was used to evaluate the influence of weed species on the species richness of native species. The equations were developed separately for each of the selected vegetation types with species richness as dependent variable and percentage cover of the three invasive plant species as independent predictor variables. The veracity of the relationship was tested using level of significance at <0.001 and the coefficient of determination (R^2).

Analysis of ecological distance was done by ordination, using the Principle Component Analysis to find the species composition among sites. Ordination methods will geometrically arrange sites so that distance between them in the graph represent their ecological distances. Sites that are close together in the graph are interpreted as similar species composition and sites that are far apart in graph as different species composition. The Stress value is calculated and less stress values give better representation.

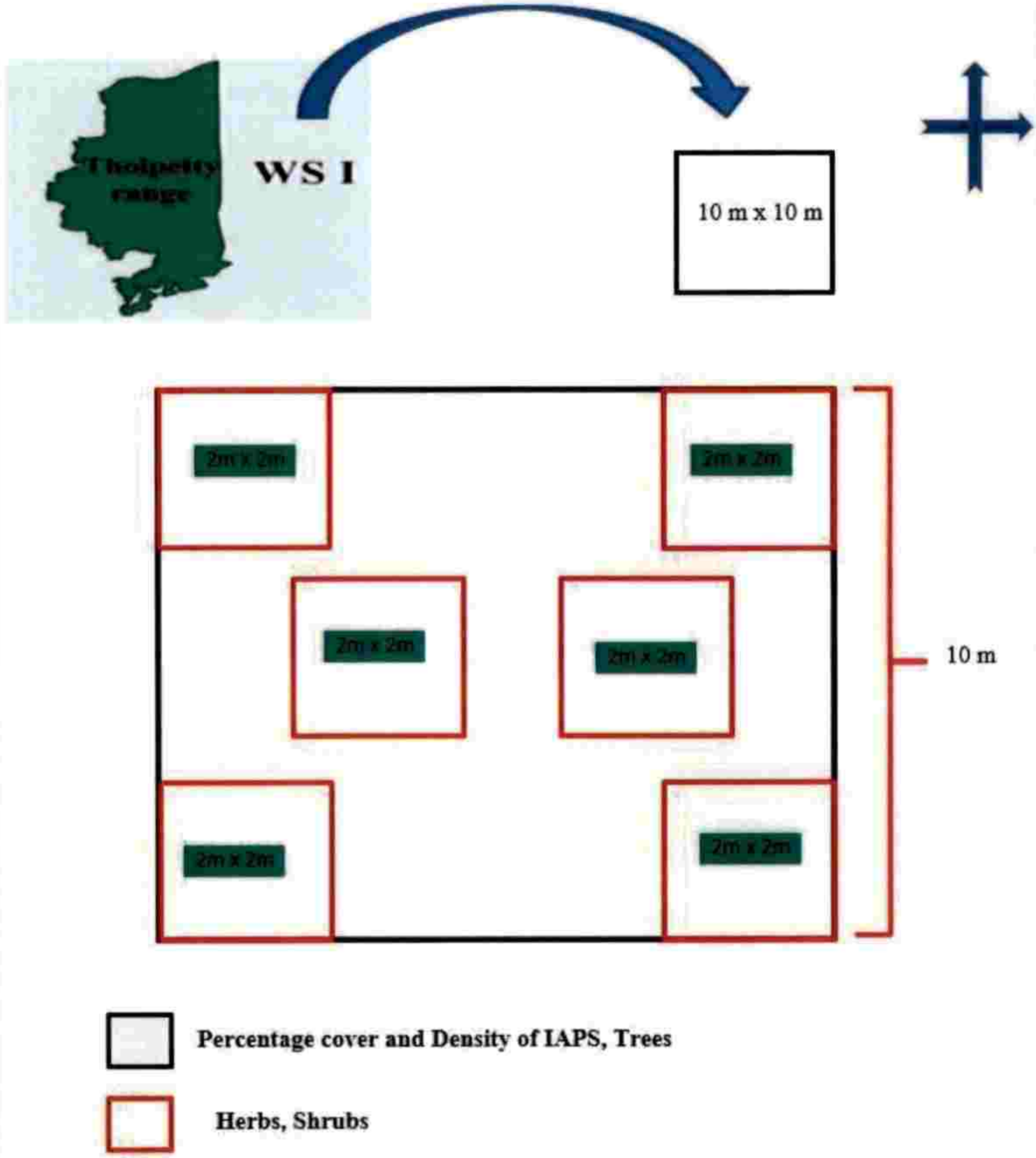


Figure 2. Diagrammatic representation of sampling method adopted

Plate 1 Spherical crown densiometer (Model A)

Plate 2. Estimation of canopy openness using spherical crown densiometer in field

RESULTS

4. RESULTS

The current study was conducted during 2018-2019 to understand the distribution characteristics and impacts of *L. camara*, *C. odorata* and *S. spectabilis* on the regeneration of other plant communities in the Tholpetty Range which is situated in the Northern portion (WS I) of Wayanad WLS of Kerala. The sanctuary consists of two units separated by a chunk of revenue land as well as RF. Tholpetty Range lies in the Northwest side of the main portion constituted by Kurichiat, Sulthan Bathery and Muthanga Ranges. The results obtained from the study are given below.

4.1 Estimation of weed cover and density

The WS I part of sanctuary was divided into three vegetation zones viz. Natural forest (NF), Plantation and *Vayal* (Table 3). The deciduous forests are predominantly seen in parts of the WS I. There were four sections which totally consist of 7767 ha of land. WS I has a single forest range called Tholpetty. Natural forest is evenly distributed with *Vayal*s in between them. Plantations were mostly constituted to the Thirulkkunu section as this region shares boundary with Thirunelli range which is part of North Wayanad Divison which is a territorial division. *Vayal*s are found more with in the Kaimaram and Dasanghatta sections (Management Plan, 2012-2022).

4.1.1 *Lantana camara* L.

L. camara was present in all the three vegetation types and it was seen as clumps. The red and cream color flower varieties of *L. camara* were seen in the sanctuary. Much branched scandent shrubs; stem 4-angled, armed with short thorns. Leaves simple, opposite, 3-6 x 2-4 cm, ovate or elliptic-ovate, apex acute to shortly acuminate, base subcordate or truncate, margin creneate-serrate, scabrous above, puberulous below, veins impressed above; petiole to 1.5 cm long. Inflorescence terminal and axillary condensed spikes; peduncle 3-4 cm long, shortly prickly. Flowers sessile, orangish-red, changing to deep red on ageing; bracts closely imbricating. They form huge thickets in open forest and plantations. It flowers throughout the year. There will be 25-28 fruits in each flower bed. *Lantana* flowers are one of the major sources of nectar for attracting sunbirds and butterflies; these enhance the rate of pollination in the sanctuary.

4.1.2 *Chromolaena odorata* (L.) R.M. King & H. Rob.

Generally, *C. odorata* is a free-standing shrub that grows to a height of 1 m. Sometimes it may reach 4 or 5 m when it climbs to trees. They are glandular hairy. Leaves simple, opposite, 8-12 x 5-8 cm, ovate, apex acute, base cuneate, crenate, hispid; petiole 2-3 cm long, cylindrical-oblong. Heads to 10 mm long, in terminal corymbose cymes; bracts 3-5-seriate, to 8 mm long, ovate, obtuse; outer smaller, inner linear, acute, 3-ribbed. Flowers few to many, similar, bisexual; corolla 5 mm long, white, tubular, 5-lobed, pubescent at apex. *C. odorata* were seen as single non branching stems at a height of 0.5 m inside the sanctuary. The seeds are black to brown-gray color that is 4 mm long.

4.1.3 *Senna spectabilis* (DC.) H.S. Irwin

S. spectabilis grows up to 15 m tall. Young parts puberulous to tomentose. Leaves alternate, rachis (including petiole) 20-33 cm long, eglandular; leaflets 8-15 pairs, 4-6 x 1.5-2.5 cm, ovate-lanceolate to lanceolate, chartaceous, acute or subacuminate, obliquely rounded at base, puberulous beneath; petioles 2-3 cm long; petiolules 2-3 mm long; stipules linear, narrowly falcate, ca 1 cm long, deciduous. Racemes are terminal or axillary, 6 -10 cm long, congested, corymbose panicles, few to many flowered.

4.1.4 Density of IAPS

Density of each weed species in all the three-vegetation types were calculated (Table 4). *Chromolaena odorata* showed highest density in all the three vegetation types. There were 8457.64 stems of *C. odorata* in one hectare of plantation followed by *L. camara* (334.11 stems ha^{-1}) and *S. spectabilis* (589.41 stems ha^{-1}). *L. camara* infestation was comparatively less than *C. odorata* considering the density. In NF there were 3734.11 stems of *C. odorata* in one hectare. The density of *L. camara* and *S. spectabilis* in NF were 1061.17and 414.11 stems ha^{-1} respectively. Here *Senna* infestation is found be less than that in the plantation in comparison with other invasive species. Density of *C. odorata* (7761.17 stems ha^{-1}) was seen in *Vayal* . 215.29 stems ha^{-1} was the density of *L. camara* in *Vayal* while the *Senna* infestation was found to be very less (34.11 ha^{-1}) (Fig. 3).

4.1.5 Percentage covers of IAPS

The percentage of area covered by IAPS in each of the selected 10m x10m plots was calculated from each vegetation type by measuring the crown area (Table 5). It was found that 19.46 % of the total sampled area in the Natural forest ecosystem was invaded by *L. camara*, 18.84 % by *C. odorata* and 15.56 % by *S. spectabilis* showed that the infestation of these three invasive species was similar in acquiring the overall sampled area. Coming to plantation, the *Lantana* infestation was only 7.57 % while *C. odorata* invades 24.58 % which showed highest infestation in this ecosystem. *S. spectabilis* infestation in plantation was found to have only 8.40%. Coming to the *Vayal* ecosystem *S. spectabilis* infestation was 0.37 % which was negligible compared to the percentage cover of other two invasive species. In *Vayal*, out of the total sampled area it was *C. odorata* which invades major portion with 46.19 % (Fig. 4).

Table 3. Area covered by each vegetation type in Tholpetty Range

Vegetation type	**Area (ha)**	**Area (km^2)**
Natural forest (NF)	3764.5	37.64
Plantation	3840.5	38.40
Vayal (Swamps/ low lying grassland)	162	1.62
Total	7767	77.67

Table 4. Density of IAPS in each vegetation type

Vegetation type	**Density of IAPS (Number of stems /hectare)**		
	C. odorata	*L. camara*	*S. spectabilis*
Plantation	8457.64 ± 27.52	334.11 ± 1.02	589.41± 2.67
Natural forest (NF)	3734.11 ± 5.65	1061.17 ± 2.75	414.11 ± 1.55
Vayal (Swamps/ low lying grassland)	7761.17 ± 9.74	215.29 ± 050	34.11± 0.21

Table 5. Percentage ground covered by selected IAPS in each vegetation type

Vegetation type	**Percentage covers of IAPS (%)**		
	C. odorata	*L. camara*	*S. spectabilis*
Plantation	24.58 ± 3.06	7.57 ± 1.96	8.40 ± 2.68
Natural forest	18.84 ± 3.09	19.46 ± 3.43	15.56 ± 3.85
Vayal (Swamps/ low lying grassland)	46.19 ± 4.03	4.43 ± 1.46	0.37 ± .0.24

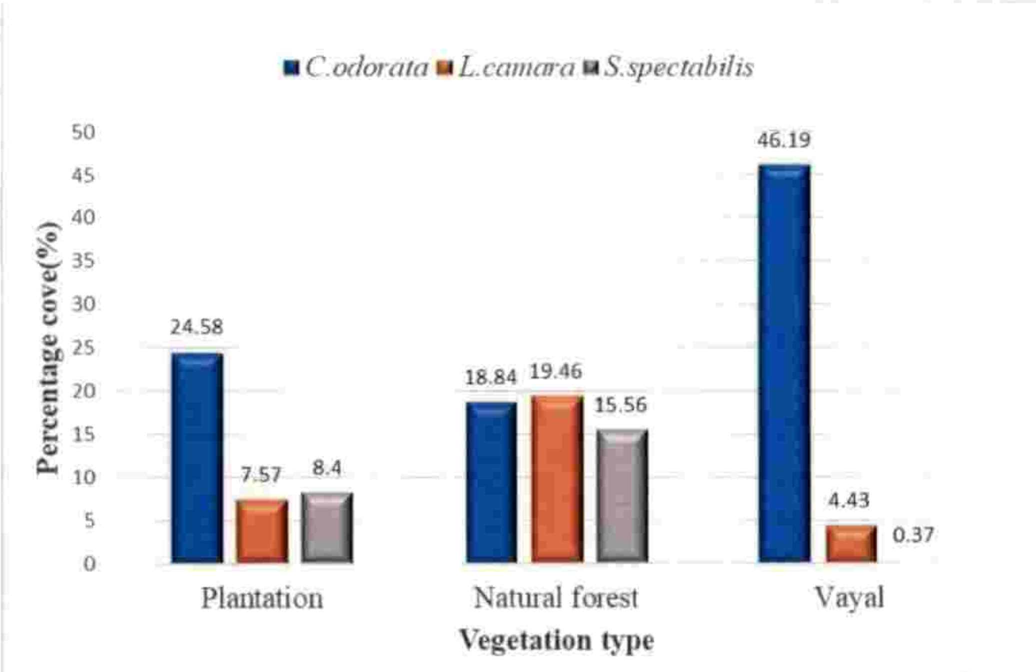


Figure 3. Density of IAPS in each vegetation type

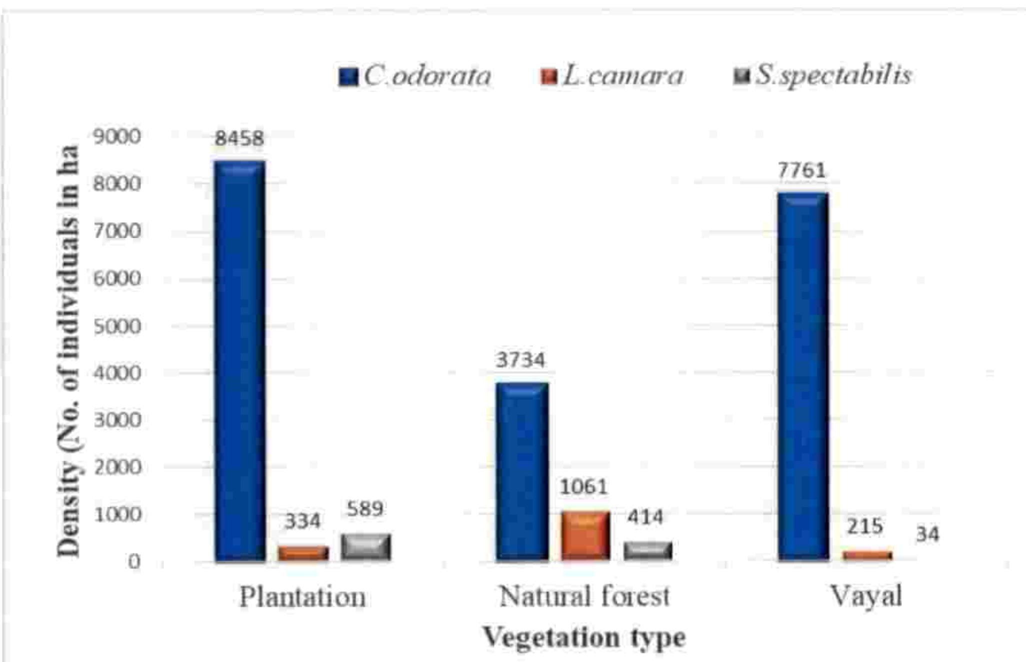


Figure 4. Percentage ground covered by selected IAPS in each vegetation type

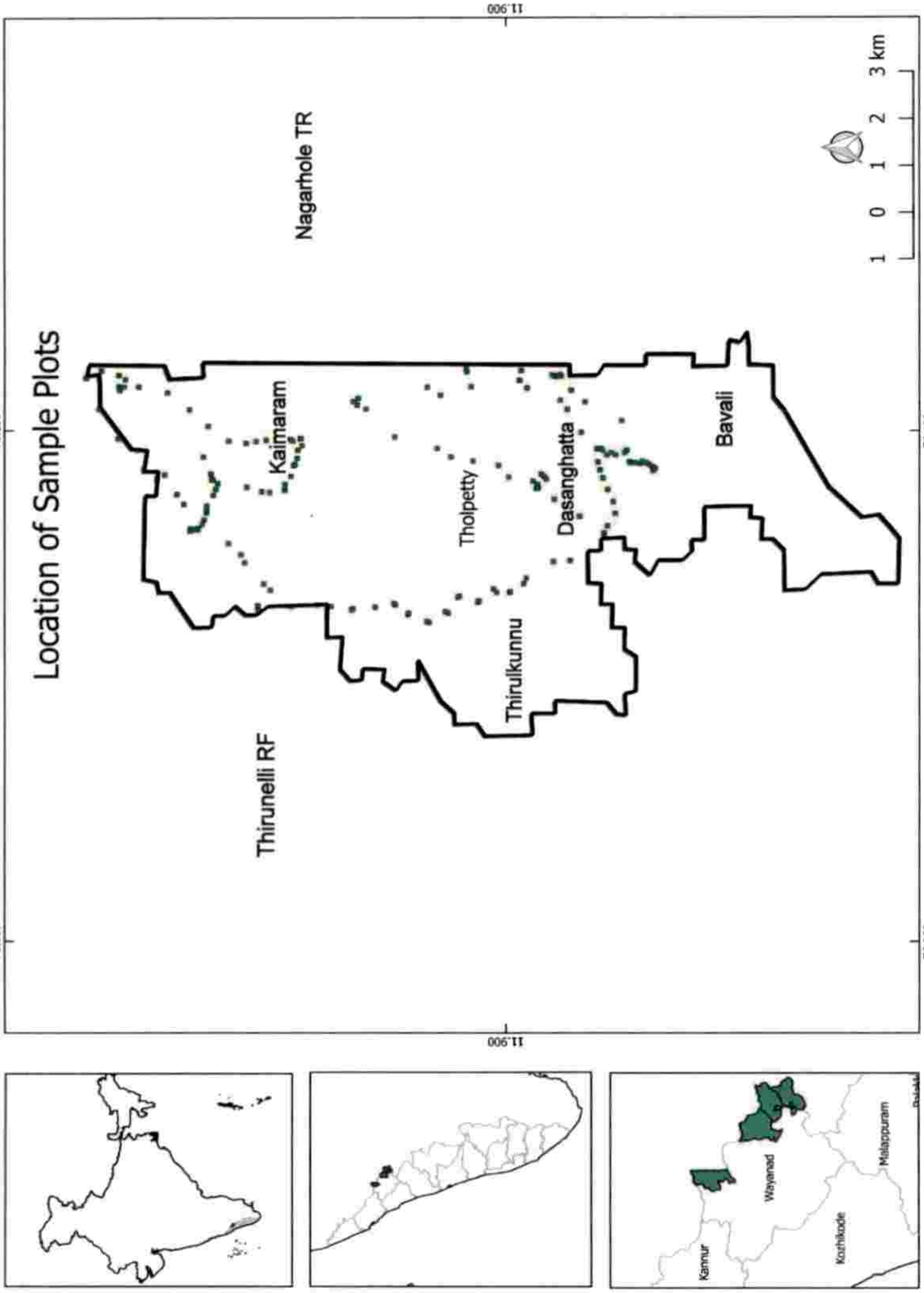


Figure 5. GPS locations of sample plots taken in WS I part of Wayanad WLS

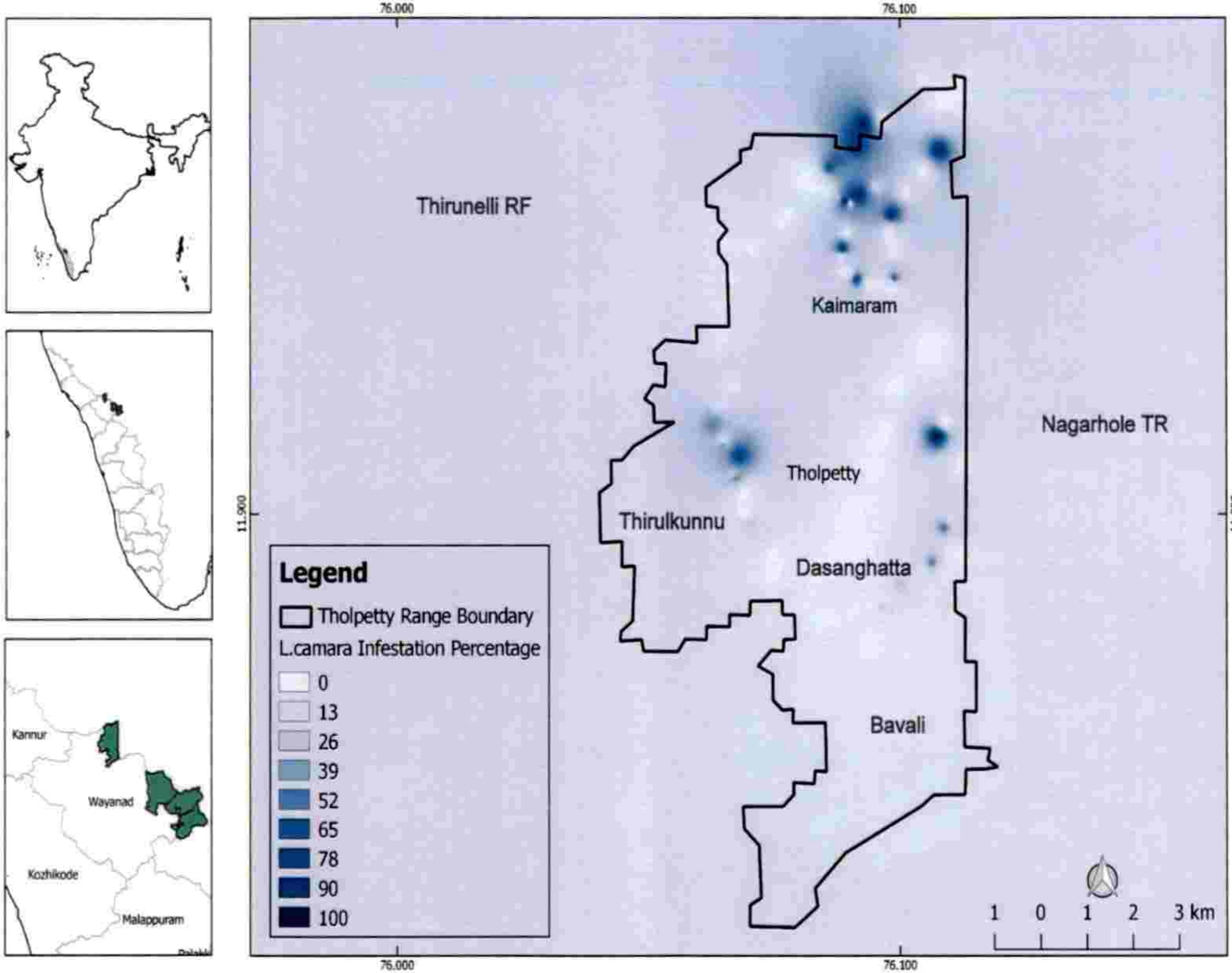


Figure 6. Distribution of *L.camara* in WS I part of Wayanad WLS

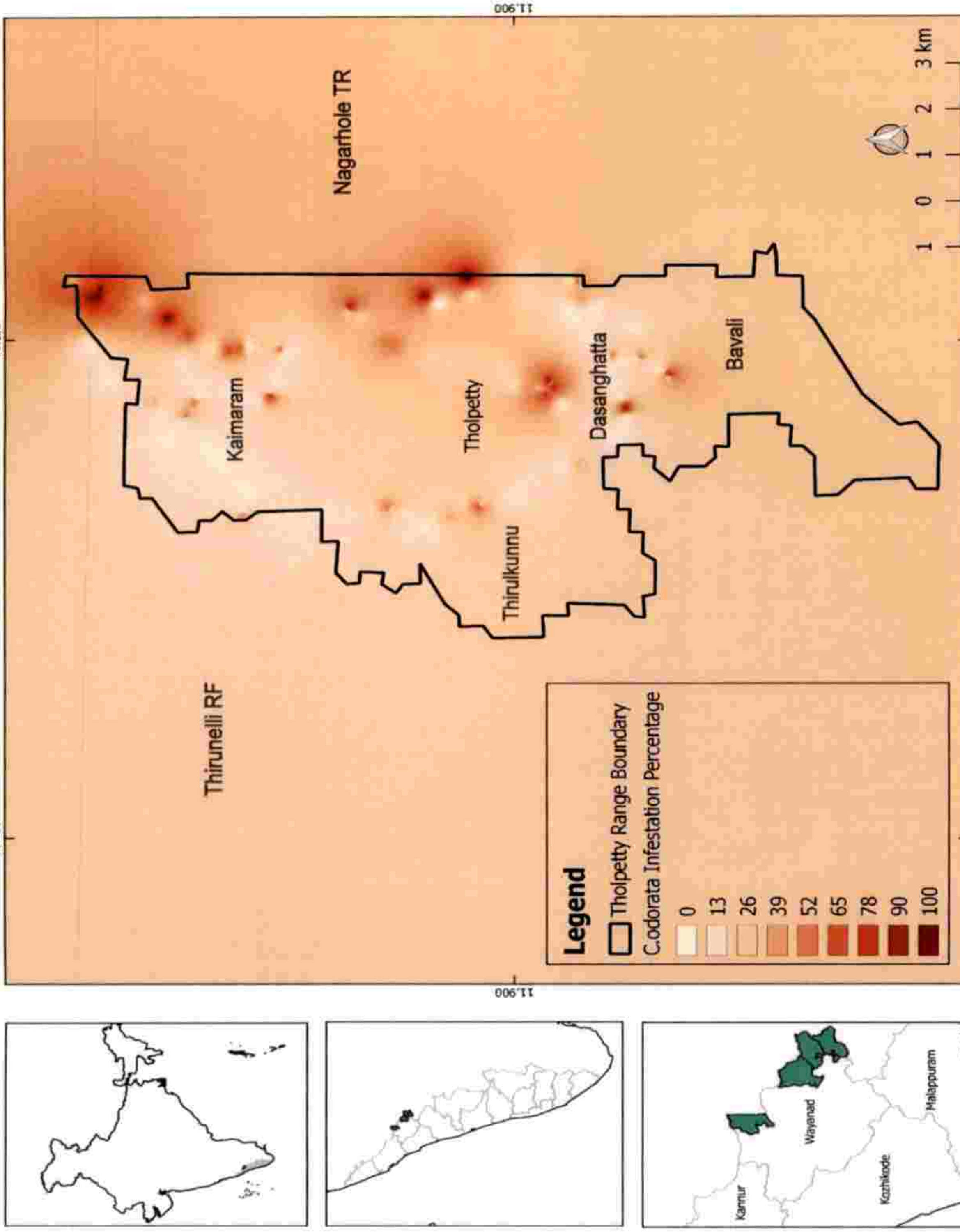


Figure 7. Distribution of *C.odorata* in WS I part of Wayanad WLS

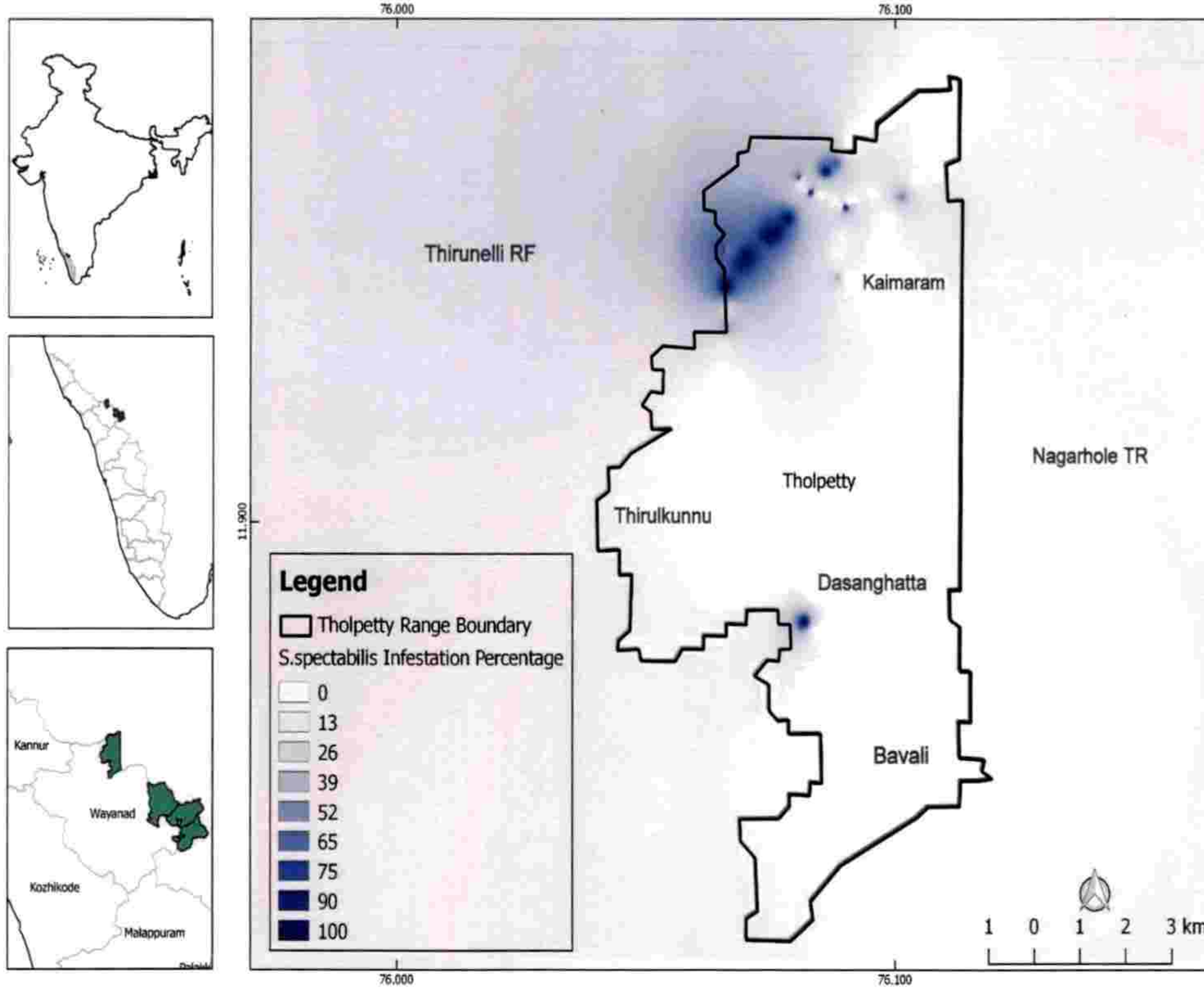


Figure 8. Distribution of *S.spectabilis* in WS I part of Wayanad WLS

4.2 Distribution of selected IAPS

For the study in the selected ecosystems of the WS I of Wayanad WLS, GPS locations of 255 plots were taken with 85 plots in each vegetation type (5 control plots). The locations covered 0.025 km^2 which is 0.03% percentage of the WS I (Fig.5).

4.2.1 *L. camara*

L.camara was distributed all over the sanctuary except in the southern regions (Fig. 6). High invasion of *L. camara* was seen in the Kaimaram and Thirulkunnu sections. Kaimaram shares boundary with Nagarhole Tiger Reserve and Thirulkunnu section shares boundary with Thirunelli RF of North Wayanad division. Dasanghatta section had severe invasion but not like in Kaimaram and Dasanghatta sections. Bavali section which lies to the southern region had minimum invasion of *L.camara.*

4.2.2 *C. odorata*

C. odorata had invaded all parts of WS I. High invasion of *Chromolaena* was found in Kaimaram and Dasnghatta sections which were directly shares the boundary with Nagarhole Tiger reserve of Karnataka (Fig. 7). Maximum invasion were found within the boundaries. Thirulkunnu section that sharing the boundary with Thirunelli RF also had invasions. Bavali section had comparatively less invasion and found with in the section and not near the boundaries.

4.2.3 *S. spectabilis*

In WS I of the Wayanad wildlife sanctuary *S.spectabilis* was mainly distributed in the Kaimaram section near the boundary between Thirunelli RF (Fig. 8). It was also found near the boundary between Nagarhole TR and Kaimaram section. It was also found in the Dasnghatta section. Thirulkunnu had very less invasion of *Senna* and Bavali section had almost no traces of the invasion of *Senna* which is the southernmost region of WS I Sharing boundary with the Begur RF. *Senna* infestation is on progress in these areas which could eventually took over all these regions in as shorter span of time. Currently 0.7% of total studied plots were covered with *Senna*. In a particular 10 m x 10 m sample plot, *Senna* had an average percentage cover of 12 m^2

4.3 Assessment of other vegetation characters

Comparatively high species richness was found in Natural forest than in Plantation and *Vayal*. In natural forest there were 103 plant species followed by Plantation with 73 species and *Vayal* with 70 plant species. 60 trees, 33 shrubs, 36 herbs and 11 climbers were found within the recorded plants species from entire ecosystems (Table 6). In Natural forest 50% of vegetation was trees, 24% were shrubs, 17 % were herbs and 9 % were climbers (Fig. 9). In plantation trees were found be more (42%) and climbers were less (8%) (Fig. 9) while in *Vayal* herbs were found be more than any other vegetation type (39%) (Fig. 9).

Each ecosystem showed uniqueness in the presence of certain species. Within the tree species, *Annona squamosa, Anogeissus latifolia, Butea monosperma, Cassia fistula, Lagerstroemia microcarpa, Lannea coromandelica, Naringi crenulata, Olea dioica, Pterocarpus marsupium, Shorea roxburghii, Syzygium cumini var. cumini, Tabernamontana alternifolia, Tectona grandis, Terminalia bellirica* and *Terminalia elliptica* were seen in all the three vegetation types. *Aporosa cardiosperma, Carallia brachiate, Dalbergia lanceolaria, Diospyros melanoxylon, Elaeocarpus variabilis, Gmelina arborea, Hydnocarpus pentandra, Miliusa tomentosa, Pongamia pinnata, Streblus asper Terminalia paniculata* and *Vitex altissima* were only found in natural forest. The species that were seen only in *Vayal* were *Careya arborea* and *Trewia nudiflora*. The species like *Ailanthus triphysa, Elaeocarpus tuberculatus, Mallotus tetracoccus* were only present in plantation.

Centella asiatica, Chamaecrista absus, Clerodendrum infortunatum and *Lindernia crustacea* are the herbs which were only seen in Natural forest. *Acalypha paniculata, Desmodium gangeticum, Gomphrena celosioides* were only seen in plantation. Species which were only seen in *Vayal* were *Arundinella leptochloa, Axonopus compressus, Cyperus pilosus, Desmodium trifolium, Digitaria ciliaris, Grangea maderaspatana, Jansenella griffithiana* and *Kyllinga nemoralis.* The herbs that were seen in all the three vegetation types were *Biophytum reinwardtii, Crassocephalum crepidioides, Curculigo orchioides, Curcuma neilgherrensis, Elephantopus scaber, Eleutheranthera ruderalis, Lepidagathis incurve, Mimosa pudica, Mitracarpus hirtus* and *Senna tora.*

*Canthium coromandelicum, Clerodendrum infortunatum, Flacourtia indica, Osbeckia asper*a and *Rauvolfia serpentina* were only seen in Natural forest. In *Vayal*s *Calotropis gigantea* and *Flemingia strobilifera* were only seen. There was no species which was found only in plantation. *Catunaregam spinosa, Dendrocalamus strictus, Glycosmis pentaphylla, Sida acuta, Sida alnifolia* and *Solanum aculeatissimum* are the shrubs which were seen in all the three vegetation types. The most abundant species found in natural Forest was *Glycosmis pentaphylla* (336) and ranked 1. *Oscimum tenuifloram* (214), *Mimosa pudica* (181) and *Cipadessa baccifera*(136) were ranked 2,3 and 4 respectively (Fig.10). In plantation the most abundant species found was *Glycosmis pentaphylla* (876) and *Tectona grandis*(436) (Fig.11). The most abundantly found species in *Vayal* was *Arundinella leptochloa* (2485) (Fig. 12).

From the 11 climbers found within the three ecosystems, *Hemidesmus indicus* and *Ziziphus oenoplia* were the only climbers seen in all the vegetation types. *Caesalpinia mimosoides*, *Cosmostigma racemosum, Elaeagnus kologa* and *Piper nigrum* were seen only in Natural forest. *Chonemorpha fragrans* was the only climber seen in *Vayal*. Just like the shrubs, there were no specific climber species found in plantation.

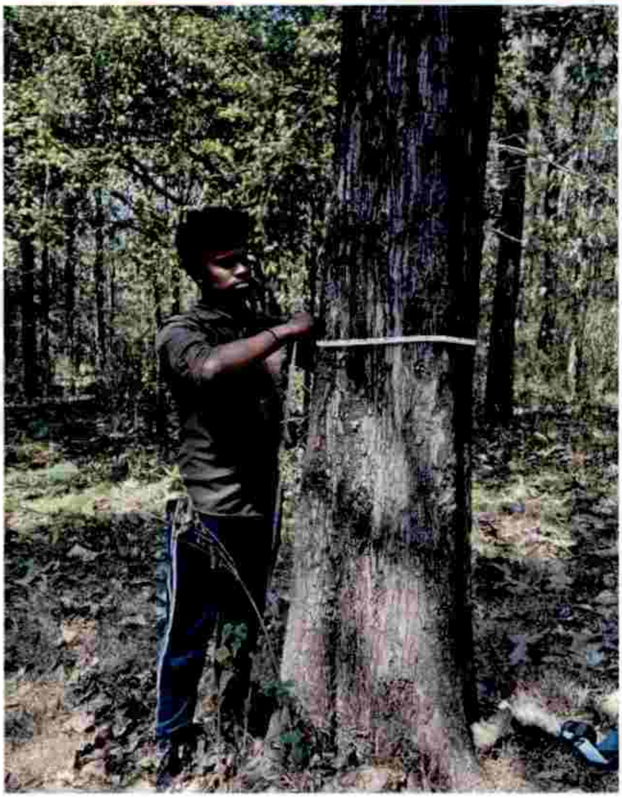


Plate 3. Assessment activities carried out in Wayanad Wildlife Sanctuary I

Table 6. List of plant species in the WS I of Wayanad WLS

Sl no.	Species	Category	NF	Plantation	*Vayal*
1	*Acacia sinuata*	S	-	-	+
2	*Anisomeles malabarica*	S	+	+	-
3	*Ageratina adenophora*	S	-	+	+
4	*Alstonia scholaris*	T	+	-	+
5	*Acalypha paniculata*	H	-	+	-
6	*Ageratum conyzoides*	H	+	-	+
7	*Ailanthus triphysa*	T	-	+	-
8	*Annona squamosa*	T	+	-	+
9	*Anogeissus latifolia*	T	+	+	+
10	*Aporosa cardiosperma*	T	+	-	-
11	*Arundinella leptochloa*	H	-	-	+
12	*Axonopus compressus*	H	-	-	+
13	*Baliospermum montanum*	S	-	-	+
14	*Asclepias curassavica*	S	+	+	+
15	*Briedelia retusa*	T	+	-	+
16	*Bombax ceiba*	T	+	+	-
17	*Bauhinia malabarica*	T	-	-	+
18	*Bauhinia racemosa*	T	+	+	-
19	*Biophytum reinwardtii*	H	+	+	+
20	*Butea monosperma*	T	+	+	+
21	*Caesalpinia mimosoides*	C	+	-	-
22	*Caesalpinia sappan*	T	+	+	-
23	*Calotropis gigantea*	S	-	-	+
24	*Calycopteris floribunda*	C	+	+	-
25	*Canthium coromandelicum*	S	+	-	-
26	*Carallia brachiata*	T	+	-	-
27	*Cardiospermum halicacabum*	C	+	+	-
28	*Careya arborea*	T	-	-	+
29	*Carmona retusa*	S	+	+	-
30	*Caryota urens*	T	+	+	-
31	*Canscor diffusa*	H	+	+	-
32	*Cassia fistula*	T	+	+	+
33	*Catunaregam spinosa*	S	+	+	+
34	*Centella asiatica*	H	+	-	-
35	*Chamaecrista absus*	H	+	-	-
36	*Chonemorpha fragrans*	C	-	-	+
37	*Cinnamomum veerum*	T	+	+	-

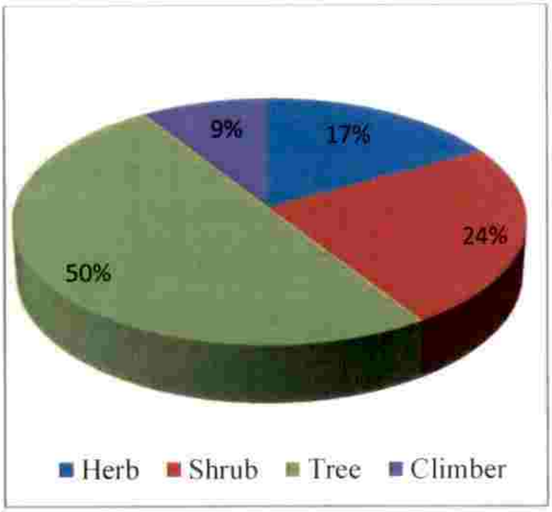
38	*Cipadessa baccifera*	S	+	+	-
39	*Clerodendrum infortunatum*	S	+	-	-
40	*Cosmostigma racemosum*	C	+	-	-
41	*Crassocephalum crepidioides*	H	+	+	+
42	*Curculigo orchioides*	H	+	+	+
43	*Curcuma neilgherrensis*	H	+	+	+
44	*Cyclea peltata*	C	+	+	-
45	*Cyperus pilosus*	H	-	-	+
46	*Dalbergia lanceolaria*	T	+	-	-
47	*Dalbergia latifolia*	T	-	+	+
48	*Dendrocalamus strictus*	S	+	+	+
49	*Desmodium gangeticum*	H	-	+	-
50	*Desmodium heterocarpon*	S	+	+	-
51	*Desmodium laxiflorum*	H	+	+	-
52	*Desmodium pulchellum*	S	+	+	-
53	*Desmodium trifolium*	H	-	-	+
54	*Digitaria ciliaris*	H	-	-	+
55	*Diospyros melanoxylon*	T	+	-	-
56	*Elaeagnus kologa*	C	+	-	-
57	*Elaeocarpus tuberculatus*	T	-	+	-
58	*Elaeocarpus variabilis*	T	+	-	-
59	*Elephantopus scaber*	H	+	+	+
60	*Eleutheranthera ruderalis*	H	+	+	+
61	*Eragrostis tenella*	H	-	-	+
62	*Eucalyptus globulus*	T	-	+	+
63	*Flacourtia indica*	S	+	-	-
64	*Flemingia strobilifera*	S	-	-	+
65	*Glycosmis pentaphylla*	S	+	+	+
66	*Gmelina arborea*	T	+	-	-
67	*Grangea maderaspatana*	H	-	-	+
68	*Grewia tiliifolia*	T	+	+	-
69	*Haldina cordifolia*	T	+	-	+
70	*Helicteres isora*	S	+	+	-
71	*Hemidesmus indicus*	C	+	+	+
72	*Hydnocarpus pentandra*	T	+	-	-
73	*Hyptis suaveolens*	S	+	+	-
74	*Imperata cylindrica*	H	-	-	+
75	*Jansenella griffithiana*	H	-	-	+
76	*Justicia adhatoda*	S	+	+	+

68

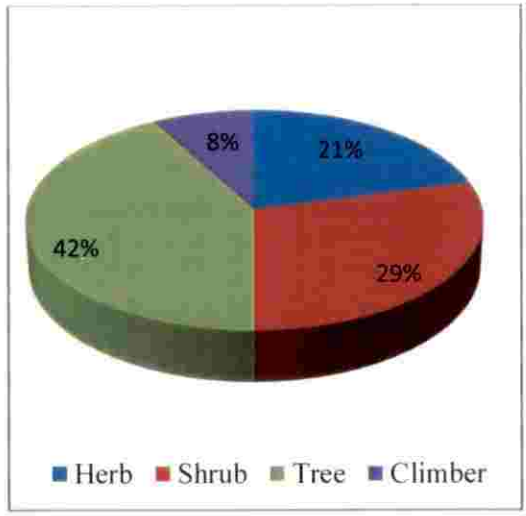
77	*Kydia calycina*	T	+	-	-
78	*Lagerstroemia microcarpa*	T	+	+	+
79	*Lagerstroemia speciosa*	T	+	-	-
80	*Lannea coromandelica*	T	+	+	+
81	*Lepidagathis incurva*	H	+	+	+
82	*Leucaena leucocephala*	H	+	-	-
83	*Leucas asper*	H	+	-	+
84	*Lindernia crustacea*	H	+	-	-
85	*Ludwigia peruviana*	S	-	-	+
86	*Mallotus tetracoccus*	T	-	+	-
87	*Mangifera indica*	T	+	-	-
88	*Melastoma malabathricum*	S	+	-	+
89	*Melia azedarach*	T	+	+	-
90	*Melia dubia*	T	+	+	-
91	*Mikania micrantha*	C	-	+	-
92	*Miliusa tomentosa*	T	+	-	-
93	*Mimosa pudica*	H	+	+	+
94	*Mimusops elengi*	T	+	+	-
95	*Mitracarpus hirtus*	H	+	+	+
96	*Mitracarpus hirtus*	H	-	-	+
97	*Naringi crenulata*	T	+	+	+
98	*Neolamarckia cadamba*	T	+	-	+
99	*Olea dioica*	T	+	+	+
100	*Osbeckia aspera*	S	+	-	-
101	*Ocimum tenuiflorum*	S	+	+	-
102	*Oscimum gratissimum*	S	+	+	-
103	*Panicum trypheron*	H	-	-	+
104	*Persea macrantha*	T	+	+	-
105	*Phyllanthus emblica*	T	+	-	+
106	*Piper nigrum*	C	+	-	-
107	*Pogostemon purpurascens*	H	-	+	-
108	*Pongamia pinnata*	T	+	-	-
109	*Premna mollissima*	T	+	-	-
110	*Pterocarpus marsupium*	T	+	+	+
111	*Rauvolfia serpentina*	S	+	-	-
112	*Rhynchospora corymbosa*	H	-	-	+
113	*Sacciolepis indica*	H	-	-	+
114	*Schleichera oleosa*	T	+	+	-
115	*Schrebera swietenioides*	T	+	-	-

116	*Semecarpus anacardium*	T	-	+	-
117	*Senna tora*	H	+	+	+
118	*Shorea roxburghii*	T	+	+	+
119	*Sida acuta*	S	+	+	+
120	*Sida alnifolia*	S	+	+	+
121	*Sida rhombifolia*	S	-	+	-
122	*Solanum aculeatissimum*	S	+	+	+
123	*Spathodea campanulata*	T	+	-	-
124	*Sporobolus tenuissimus*	H	-	-	+
125	*Stachyphrynium jamaicensis*	S	+	+	-
126	*Streblus asper*	T	+	-	-
127	*Syzygium cumini var. cumini*	T	+	+	+
128	*Tabernamontana alternifolia*	T	+	+	+
129	*Tamilnadia uliginosa*	T	+	-	+
130	*Tectona grandis*	T	+	+	+
131	*Terminalia bellirica*	T	+	+	+
132	*Terminalia cuneata*	T	+	-	+
133	*Terminalia elliptica*	T	+	+	+
134	*Terminalia paniculata*	T	+	-	-
135	*Themeda triandra*	H	-	-	+
136	*Trewia nudiflora*	T	-	-	+
137	*Uraria rufescens*	S	+	-	-
138	*Triumfetta rhomboidea*	S	+	+	-
139	*Vitex altissima*	T	+	-	-
140	*Ziziphus oenoplia*	C	+	+	+
	Total		**103**	**73**	**70**

(C- Climber, H- Herb, S- Shrub, T- Tree, '+' Present, '-' Absent)



(a)



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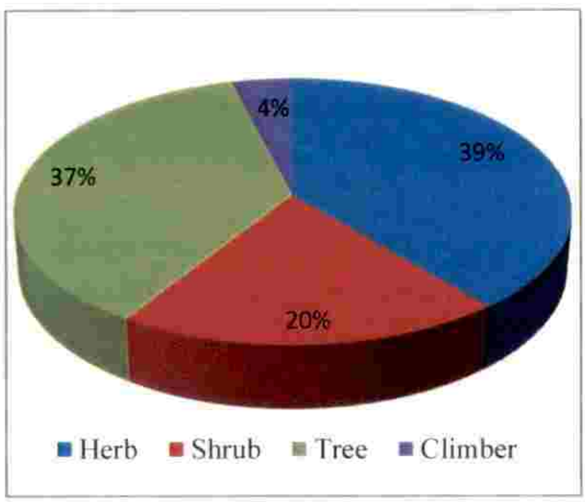


(c)

Figure 9. Percentage distribution of vegetation in Natural forest (a), Plantation(b), and *Vayal* (c)

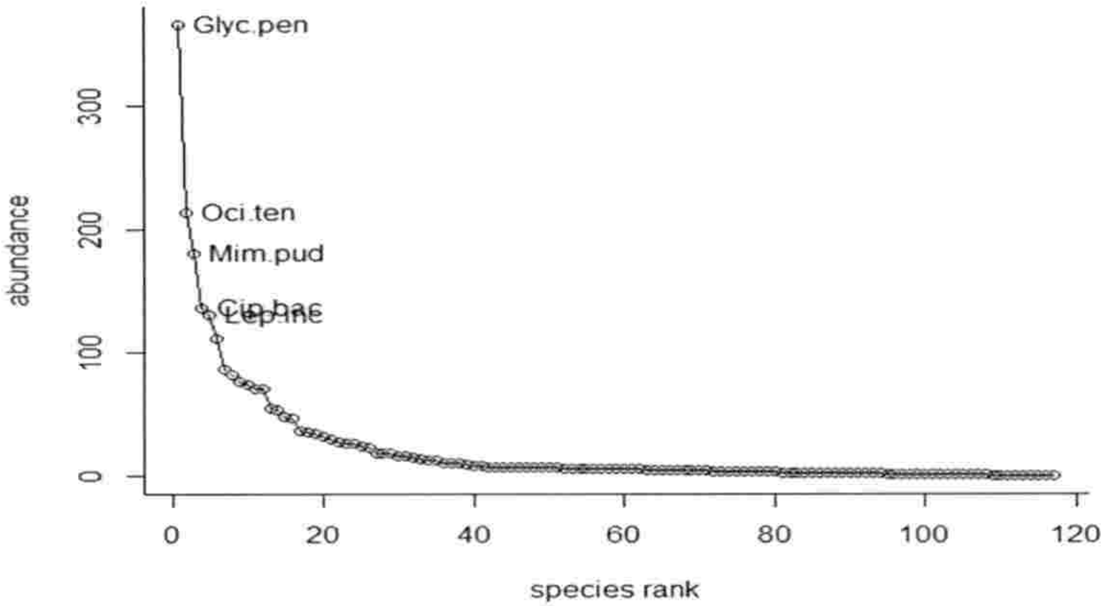


Figure 10. Abundance of native species in NF

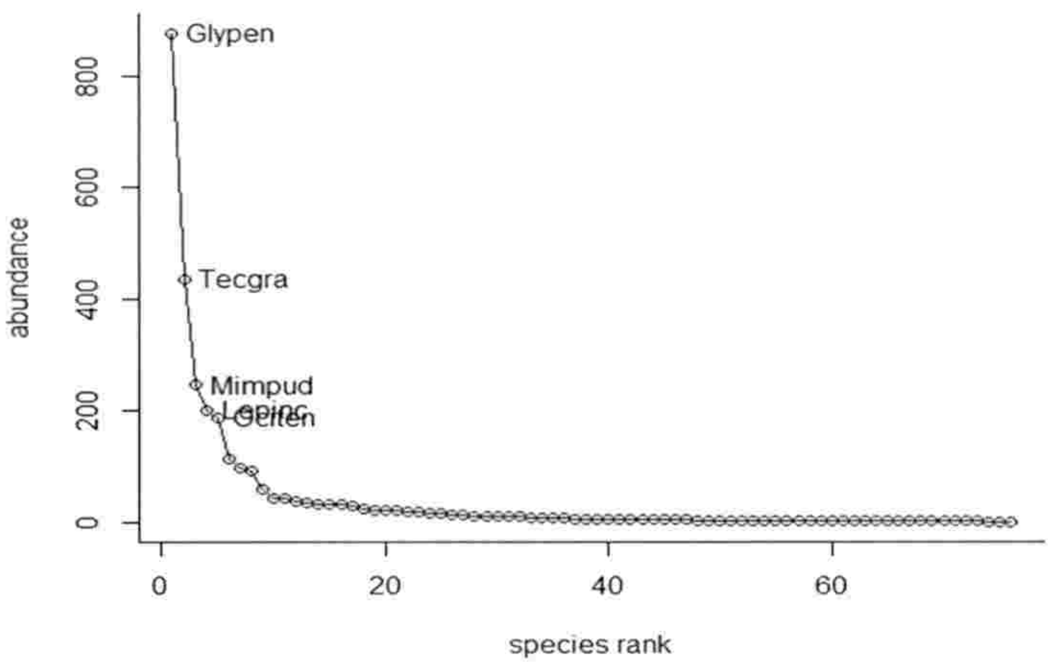


Figure 11. Abundance of native species and rank in Plantation

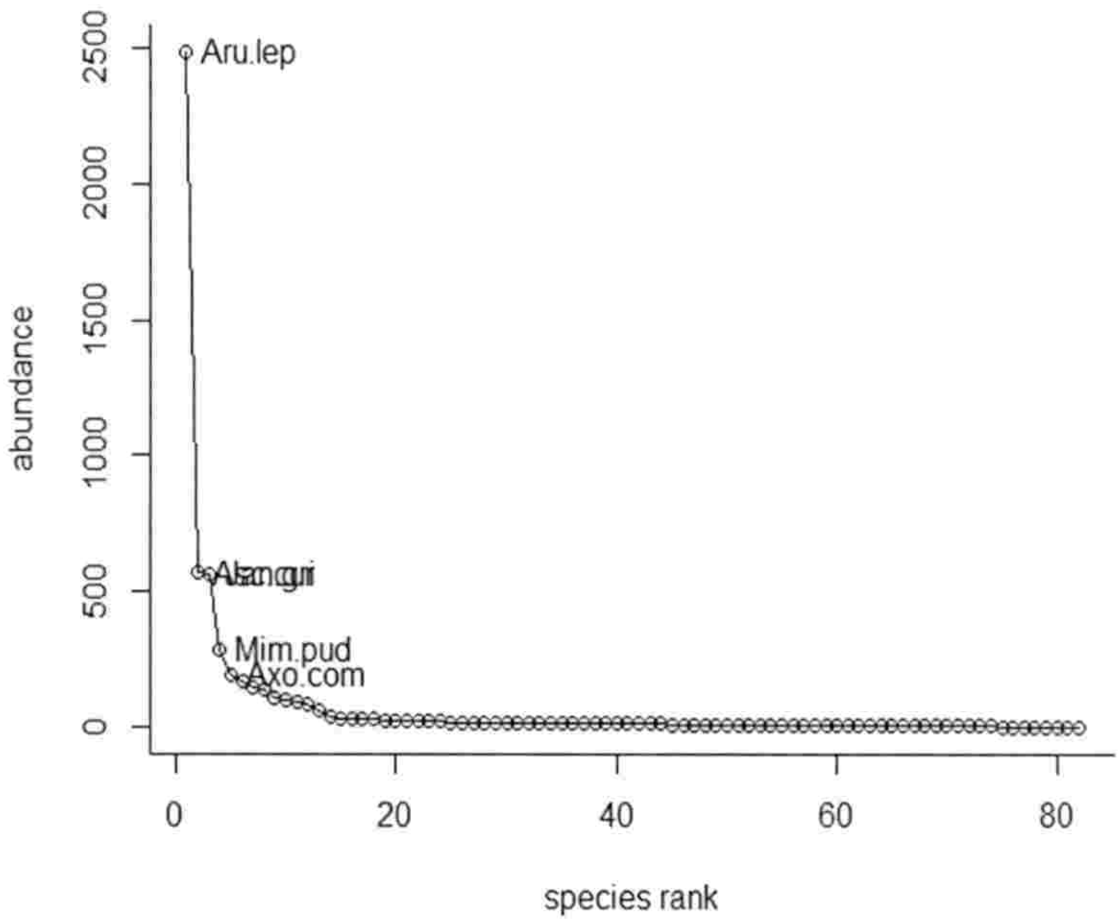
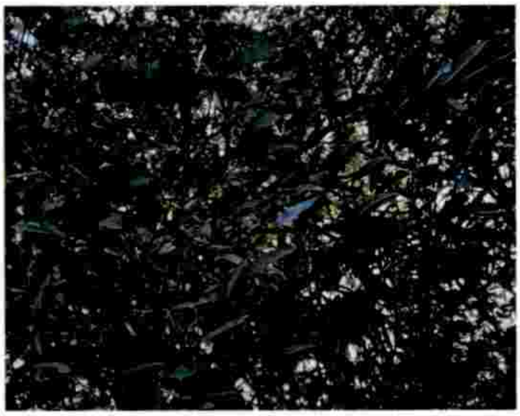


Figure 12. Abundance of native species in *Vayal*

From WS I of Wayanad WLS, about 140 plant species was identified (Table 4). Maximum number of plant species (113) was obtained from control plot. It accounts for 80.71% of the total plant species identified from entire study area. (Table 7). *C. odorata* infested areas had 96 native species followed the control plot and *L. camara* infested areas has had 67 native species. *S. spectabilis* invaded sites had only 20 plant species constituting about 14.2% which was very less. Majority of the areas had the combination of *Lantana* and *Chromolaena*. 64 plants were identified from LC areas and was 45.71% of entire native plant species identified from the study area. *Chromolaena* and *Senna* combined plots showed more serious effect and only 9 species were found which was only 6.4%. *Lantana* and *Senna*



Alstonia scholaris

Bauhinia racmeosa

Caesalpinia mimosoides

Careya arboea

Curculigo orchioides

Cyclea peltata

Plate 4. Common species found in Wayanad WS I

Dalbergia latifolia

Desmodium triflorum

Elephantopus scaber

Grewia tilifolia

Glycosmis pentaphylla

Pterocarpus marsupium

Plate 5. Common species found in Wayanad WS I

Melastoma malabathricum

Senna tora

Sida acuta

Sida alnifolia

Shorea roxburghii

Terminalia paniculata

Plate 6. Common species found in Wayanad WS I


Terminalia eliptica


Tabernaemontana alternifolia


Biophytum reinwardtii


Calycopteris floribunda


Cinnamomum verum


Ziziphus oenoplia

Plate 7. Common species found in Wayanad WS I

affected plot had the least species richness (7). There were 14 plant species which showed its presence in the areas were all the three Invasive Alien Plant Species invaded. In control plots the native species found were *Aporosa cardiosperma, Canthium coromandelicum, Clerodendrum infortunatum, Elaeagnus kologa, Elaeocarpus tuberculatus, Flacourtia indica, Flemingia strobilifera, Hydnocarpus pentandra, Lindernia crustacean, Ludwigia peruviana, Mallotus tetracoccus, Melia azedarach, Miliusa tomentosa, Osbeckia aspera, Piper nigrum, Rauvolfia serpentine* and *Streblus asper*. In *Lantana* infected plots species like *Bauhinia racemosa, Cosmostigma racemosum* and *Elaeocarpus variabilis* were only seen. Certain species like *Calotropis gigantea, Leucaena leucocephala, Melastoma malabathricum* and *Stachyphrynium jamaicensis* were only seen in *Chromolaena* infected plots.

Table 7: Plant species recorded in different weed category areas in WS I, Wayanad WLS

SI.No.	Species	L	C	S	LC	CS	LS	LCS	Control
1	*Anacolosa densiflora*	+	+	-	-	-	-	-	+
2	*Alstonia scholaris*	+	+	-	-	-	-	-	+
3	*Acalypha paniculata*	+	-	-	-	-	-	-	+
4	*Ageratina adenophora*	+	+	-	-	-	-	-	+
5	*Anisomeles malabarica*	+	+	-	+	-	-	-	+
6	*Acacia sinuata*	+	+	-	-	-	-	-	+
7	*Ageratum conyzoides*	+	+	-	+	-	+	-	-
8	*Ailanthus triphysa*	-	+	-	-	-	-	-	+
9	*Annona squamosa*	-	+	-	-	-	-	-	+
10	*Anogeissus latifolia*	+	-	+	+	-	-	+	+
11	*Aporosa cardiosperma*	-	-	-	-	-	-	-	+
12	*Arundinella leptochloa*	+	+	-	+	-	-	-	+
13	*Axonopus compressus*	-	+	-	-	-	-	-	+
14	*Asclepias curassavica*	+	+	-	-	-	-	-	-
15	*Bauhinia malabarica*	-	+	-	-	-	-	-	+
16	*Baliospermum montanum*	+	+	-	-	-	-	-	+
17	*Barleria mysorensis*	-	-	-	-	-	-	-	+

18	*Briedelia retusa*	+	+	+	-	+	-	-	+
19	*Bauhinia racemosa*	+	+	-	-	+	-	-	+
20	*Bombax ceiba*	+	-	-	-	-	-	-	-
21	*Biophytum reinwardtii*	+	+	-	+	-	-	-	+
22	*Caesalpinia sappan*	+	-	-	-	-	-	-	+
23	*Butea monosperma*	+	+	-	+	-	-	+	+
24	*Caesalpinia mimosoides*	+	-	-	+	-	-	-	-
25	*Calotropis gigantea*	-	+	-	-	-	-	-	-
26	*Calycopteris floribunda*	-	+	-	+	-	-	-	+
27	*Canthium coromandelicum*	-	-	-	-	-	-	-	+
28	*Carallia brachiata*	-	-	-	+	-	-	-	+
29	*Cardiospermum halicacabum*	-	-	+	+	+	-	-	+
30	*Careya arborea*	+	+	-	-	-	-	-	+
32	*Caryota urens*	+	+	-	-	-	-	-	+
33	*Cassia fistula*	+	+	+	+	-	+	-	+
34	*Catunaregam spinosa*	+	+	-	-	-	-	-	+
35	*Centella asiatica*	-	-	+	-	-	-	-	+
36	*Canscor diffusa*	-	-	-	-	-	-	-	+
38	*Chonemorpha fragrans*	+	+	-	+	-	-	-	-
39	*Cinnamomum veerum*	-	+	-	-	-	-	-	+
40	*Cipadessa baccifera*	+	+	-	+	-	-	+	+
41	*Clerodendrum infortunatum*	-	-	-	-	-	-	-	+
42	*Cosmostigma racemosum*	+	-	-	-	-	-	-	-
43	*Crassocephalum crepidioides*	+	+	+	+	-	+	+	+
44	*Curculigo orchioides*	+	+	-	+	-	-	-	+
45	*Curcuma neilgherrensis*	+	+	-	+	-	-	+	+
46	*Cyclea peltate*	+	+	-	-	-	-	-	+
47	*Cyperus pilosus*	-	+	-	+	-	-	-	+
48	*Dalbergia lanceolaria*	+	+	-	+	-	-	-	-
49	*Dalbergia latifolia*	+	+	-	+	-	-	+	+
50	*Dendrocalamus strictus*	-	+	-	-	+	-	+	+
51	*Desmodium heterocarpon*	-	+	-	+	-	-	-	-
52	*Desmodium laxiflorum*	-	+	-	+	-	-	-	+
53	*Desmodium pulchellum*	+	+	-	+	-	-	-	-
54	*Desmodium trifolium*	-	+	-	-	-	-	-	+
55	*Digitaria ciliaris*	+	+	-	+	-	-	-	+
56	*Diospyros melanoxylon*	+	-	+	+	-	-	-	+
57	*Uraria rufescens*	-	-	-	-	-	-	-	+

58	*Elaeocarpus tuberculatus*	-	-	-	-	-	-	-	+
59	*Elaeocarpus variabilis*	+	+	-	-	-	-	-	-
60	*Elephantopus scaber*	+	+	-	+	-	-	-	+
61	*Eleutheranthera ruderalis*	+	+	-	+	+	-	-	+
63	*Eragrostis tenella*	+	+	-	+	-	-	-	+
64	*Eucalyptus globulus*	-	+	+	-	-	-	-	-
65	*Flacourtia indica*	-	-	-	-	-	-	-	+
66	*Flemingia strobilifera*	-	-	-	-	-	-	-	+
67	*Glycosmis pentaphylla*	+	+	+	+	-	+	+	+
68	*Gmelina arborea*	-	+	-	+	-	-	+	+
69	*Justicia adhatoda*	-	-	-	-	-	-	-	+
70	*Grangea maderaspatana*	-	+	+	-	-	-	-	+
71	*Grewia tiliifolia*	-	+	-	+	-	-	-	+
72	*Haldina cordifolia*	-	+	+	+	+	-	+	+
73	*Helicteres isora*	+	+	+	+	-	+	+	+
74	*Imperata cylindrica*	+	-	-	-	-	-	-	+
75	*Hemidesmus indicus*	-	+	-	-	-	-	-	+
76	*Hydnocarpus pentandra*	-	-	-	-	-	-	-	+
77	*Hyptis suaveolens*	+	+	-	+	-	-	-	-
78	*Jansenella griffithiana*	+	+	-	+	-	-	-	+
79	*Kydia calycina*	-	+	-	-	-	-	-	+
80	*Lagerstroemia microcarpa*	+	+	-	+	-	-	-	+
81	*Lagerstroemia speciosa*	+	-	-	+	-	-	-	-
82	*Lannea coromandelica*	-	-	-	+	-	-	-	+
83	*Lepidagathis incurva*	-	+	+	-	-	+	-	+
84	*Leucaena leucocephala*	-	+	-	-	-	-	-	-
85	*Leucas asper*	-	+	-	-	-	-	-	+
86	*Lindernia crustacea*	-	-	-	-	-	-	-	+
87	*Ludwigia peruviana*	-	-	-	-	-	-	-	+
88	*Mallotus tetracoccus*	-	-	-	-	-	-	-	+
89	*Mangifera indica*	-	+	-	+	-	-	-	+
90	*Melastoma malabathricum*	-	+	-	-	-	-	-	-
91	*Melia azedarach*	-	-	-	-	-	-	-	+
92	*Melia dubia*	+	+	+	-	-	-	-	+
93	*Miliusa tomentosa*	-	-	-	-	-	-	-	+
94	*Mimosa diplotricha*	+	+	+	+	+	+	-	+
95	*Mimusops elengi*	+	+	-	+	-	-	-	+
96	*Neolamarckia cadamba S*	+	+	-		-	-	-	+
97	*Mitracarpus hirtus*	-	+	-	+	-	-	-	-

98	*Naringi crenulata*	-	+	-	+	-	-	-	+
99	*Olea dioica*	+	+	-	+	-	-	-	+
100	*Osbeckia aspera*	-	-	-	-	-	-	-	+
101	*Ocimum tenuiflorum*	+	-	-	-	-	-	-	+
102	*Oscimum gratissimum*	-	-	-	-	-	-	-	+
103	*Panicum trypheron*	-	+	-	+	-	-	-	+
104	*Persea macrantha*	+	+	-	+	-	-	-	+
105	*Phyllanthus emblica*	+	+	-	-	-	-	-	+
106	*Piper nigrum*	-	-	-	-	-	-	-	+
107	*Pogostemon purpurascens*	-	+	-	+	-	-	-	-
108	*Pongamia pinnata*	-	+	-	+	-	-	-	+
109	*Premna mollissima*	-	-	-	-	-	-	-	+
110	*Pterocarpus marsupium*	+	+	-	-	-	-	-	+
111	*Rauvolfia serpentina*	-	-	-	-	-	-	-	+
112	*Rhynchospora corymbosa*	-	+	-	-	-	-	-	+
113	*Sacciolepis indica*	+	+	-	+	-	-	-	-
114	*Schleichera oleosa*	+	+	-	+	-	-	-	+
115	*Schrebera swietenioides*	-	+	-	+	-	-	-	+
116	*Semecarpus anacardium*	-	+	-	-	-	-	-	+
118	*Senna tora*	+	+	-	+	-	-	-	-
119	*Shorea roxburghii*	+	+	-	+	-	-	-	+
120	*Sida acuta*	-	+	-	+	-	-	-	-
121	*Sida alnifolia*	-	+	-	+	-	-	-	+
122	*Sida rhombifolia*	-	+	-	-	-	-	-	+
123	*Solanum aculeatissimum*	+	+	-	+	-	-	+	+
124	*Spathodea campanulata*	+	+	-	+	-	-	-	+
125	*Sporobolus tenuissimus*	+	+	-	+	-	-	-	+
126	*Stachyphrynium jamaicensis*	-	+	+	-	-	-	-	-
127	*Streblus asper*	-	-	-	-	-	-	-	+
128	*Syzygium cumini var. cumini*	+	+	-	+	-	-	-	+
129	*Tabernamontana alternifolia*	+	+	+	+	-	-	-	+
130	*Tamilnadia uliginosa*	-	+	-	-	-	-	-	+
131	*Tectona grandis*	+	+	+	+	-	-	-	+
132	*Terminalia bellirica*	-	+	-	-	-	-	-	+
133	*Terminalia cuneata*	-	-	-	+	-	-	-	+
134	*Terminalia elliptica*	+	+	+	+	+	-	+	+
135	*Terminalia paniculata*	+	-	-	-	+	-	-	+
136	*Themeda triandra*	+	-	+	+	-	-	-	+
137	*Trewia nudiflora*	-	+	-	-	-	-	-	+

138	*Triumfetta rhomboidea*	-	+	-	-	-	-	-	+
139	*Vitex altissima*	-	-	-	-	-	-	+	+
140	*Ziziphus oenoplia*	-	+	-	+	-	-	-	+
	Total	67	96	20	64	9	7	14	113

(L- *Lantana* invaded, C- *Chromolaena* invaded, S- *Senna* invaded, LC- *Lantana* and *Chromolaena* invaded, CS- *Chromolaena* and *Senna* invaded, LCS- *Lantana*, *Chromolaena* and *Senna* invaded, Control- weed free area,'+' Present, '-' Absent)

4.4 Vegetation analysis

4.4.1 Species richness

In each vegetation type the mean species richness (MSR) was calculated (Table 8). Natural forest has the highest species richness value and the lowest value was in *Vayal* (Fig.13). Considering each of the seven vegetation type in all the three ecosystem control plot had shown the maximum species richness (Fig. 13). In vegetation types such as S (*S. spectabilis*), CS (*C. odorata* and *S. spectabilis*) and LCS (*L. camara, C .odorata* and *S. spectabilis*) plots the species richness were comparatively low. Within entire study area inside WS I the control plot in NF showed highest mean species richness (MSR) of 27.6 (Fig. 14). In Natural forest L, C and LC plots MSR of 11.66, 9.13 and 7.46 respectively. The MSR of CS and LS plots in Natural forest were 6.75 and 6 respectively. The LCS plot had the least MSR which was 4.6. In plantation, the maximum MSR was in control plots and was (21). The MSR of S plot in plantation has the lowest and was (4.5). The L, C and LC plots had MSR 6.3, 8.96 and 7.5 respectively. In *Vayal,* like the other ecosystems, the MSR in control plot was highest (18.8) and was followed by MSR in C (8.9) .The lowest MSR in *Vayal* was from LC plot (6.06). Studying all the MSR of Seven weed categories in three vegetation types, it was found that the control plots had the highest MSR (Fig. 12). It was followed by L and LC plots. The lowest MSR was found in S, CS and LCS plots.

Performing Tests Between-Subjects Effects the species richness of native Comparing each ecosystem type ($F_{2, 232} = 1.708$; $p>0.001$) it showed no significant variation among them and grouped in a common homogeneous subset 'a' (Table 9) which explains that each ecosystem had almost same species richness. Different weed category areas ($F_{7, 232} = 13.93$; $p<0.001$) showed significant variations between them and grouped as 'a', 'b' and 'bc' (Table 9). Control was independent from other weed category areas showed highest species richness. 'L' and 'LCS' plot is together in 'b' with similar characters. *Senna* plot is also found independent with very less species richness. Analyzing both vegetation type and weed category, the interaction between them also showed significant variation ($F_{13, 232} = 4.01$ $p<0.001$).

Table 8. Mean Species richness (MSR) among weed category areas in three vegetation types

Vegetation type	**Mean species richness among weed category areas**							
	L	C	S	LC	CS	LS	LCS	Control
Natural forest	11.66 ± 2.39	9.13 ± 1.1	7 ± 1.67	7.46 ± 0.94	6.75 ± 0.75	6 ±0	4.66 ±0.42	27.6 ±1.77
Plantation	6.33 ± 5.36	8.96 ±0.76	4.5 ± 0.86	7.55 ± 0.42	9.88 ± 2.9	6.5 ± 1.5	6 ± 0	21 ± 2.30
Vayal	9.5 ± 0.5	11.65 ± 0.89	8 ± 0	6.06 ± 0.72	9 ± 0	0	14 ± 0	18.8 ±1.31

Table 9. Mean for weed category groups in homogeneous subsets

Vegetation type	**Means for groups in homogeneous subsets**								
	L	C	S	LC	CS	LS	LCS	CON	Average
Natural forest	11.66	9.13	7	7.46	6.75	6	4.66	27.6	10.03^{a}
Plantation	6.33	8.96	4.5	7.55	9.88	6.5	6	21	8.84^{a}
Vayal	9.5	11.65	8	6.06	16	0	14	18	10.40^{a}
Average	9.16^{b}	9.91^{bc}	6.50^{c}	7.02^{bc}	10.88^{bc}	4.17^{bc}	8.22^{b}	22.20^{a}	

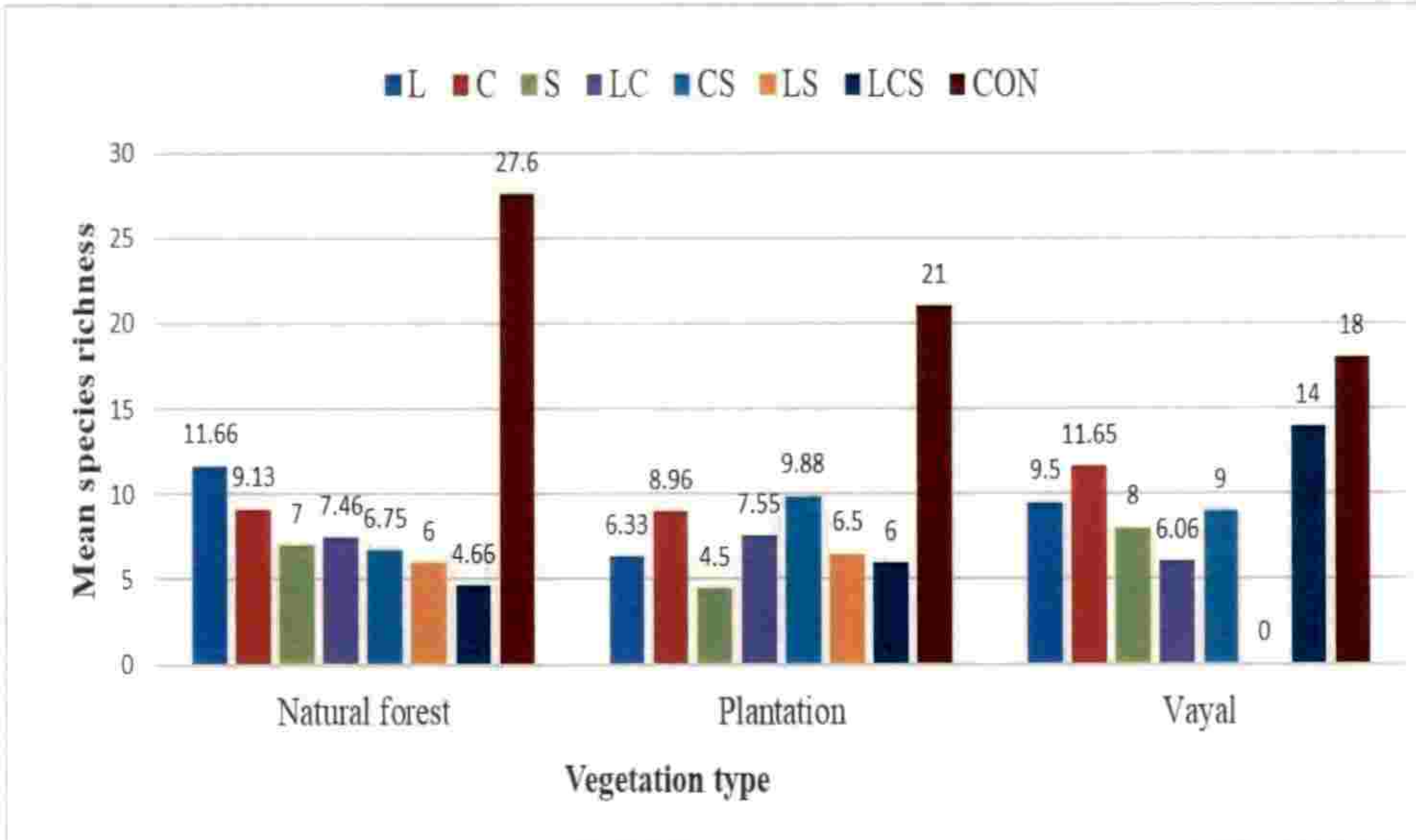


Figure 13. Mean species richness among weed category areas in three vegetation types

84

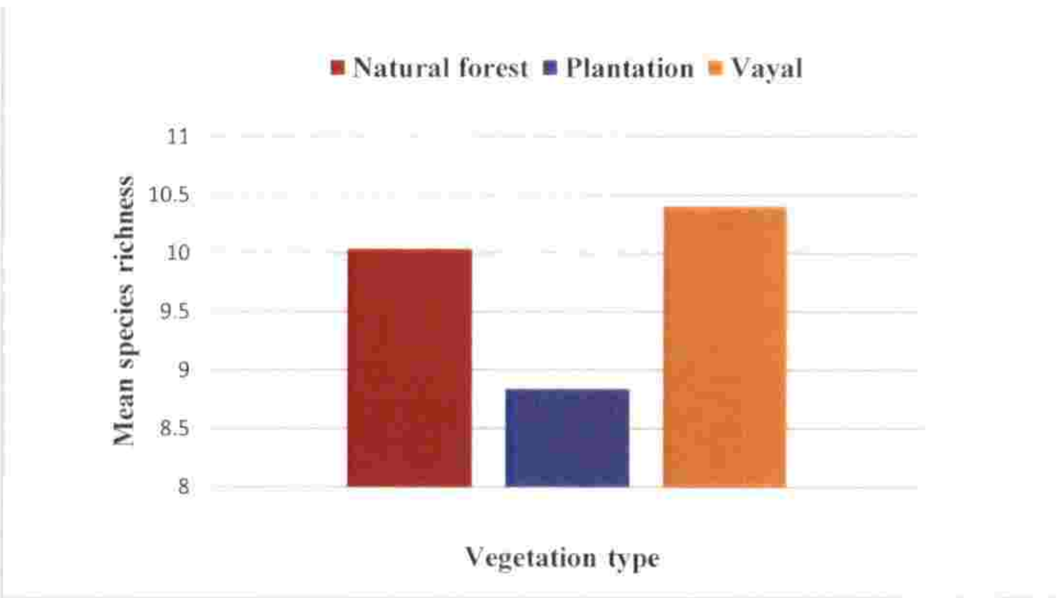


Figure 14. Means of species richness in three vegetation types

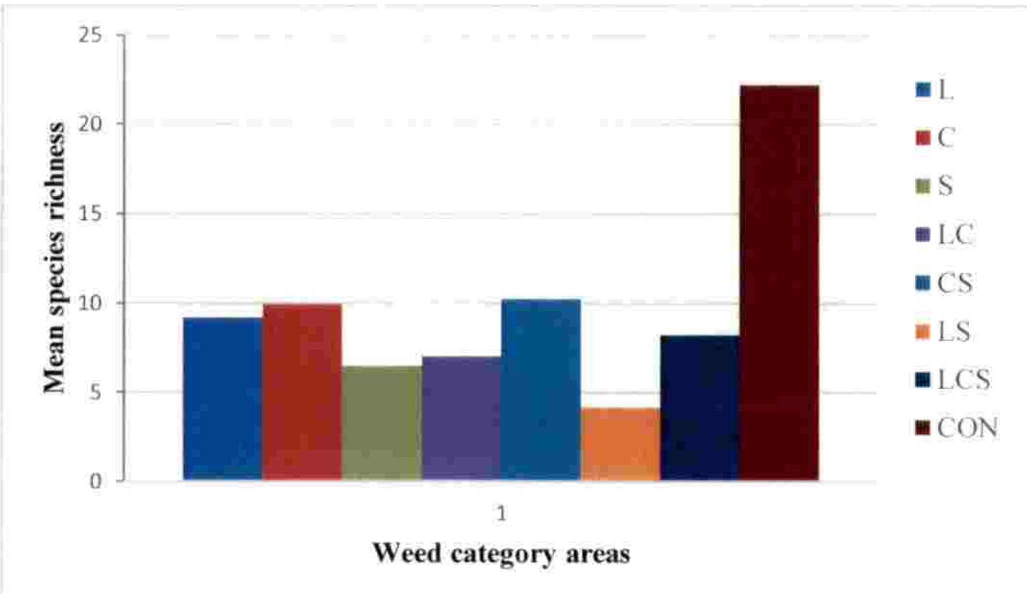


Figure 15. Means of species richness in weed category areas

4.4.2 Phytosociological analysis

The phytosociological analysis in Natural forest showed that *C. odorata* has maximum abundance (52.03) and frequency (71.9) (Table 10). *Kydia calycina* (27.3) has maximum abundance after *C.odorata* and stand second. *Oscimum tenuifloram* with abundance (23.77) comes third most abundant species. The abundance of *S. spectabilis* and *L. camara* were 22 and 19.19 respectively. The most densely seen plant species in the natural forest were *C. odorata* and *L. camara* with density 3734 ha^{-1} and 1061 ha^{-1} respectively. *Glycosmis pentaphylla* (472.9 stems ha^{-1}) were found as third densily seen species after *C. odorata* and *L. camara*. The most densely seen tree species in NF is *S. spectabilis* (414.11 stems ha^{-1}). Maximum frequency was shown by *C .odorata* (71.9) followed by *L. camara* (55). *Cipadessa buccifera* (45.8). *S. spectabilis* had frequency 18.52. *Cassia fistula* was the tree species with highest frequency (32.9). Among the first five highly dense plant species in NF, four were IAPS. It was *Neolamarckia cadamba* which had the lowest frequency, abundance and density in NF.

The phytosociological analysis in plantation, the highest density was for *C.odorata* (8457 stems ha^{-1}) followed by *Glycosmis pentaphylla* (1030 stems ha^{-1}) (Table 11). *S. spectabilis* had 589 stems ha^{-1} and was largest number among trees. *Tectona grandis* had 512 stems ha^{-1}. *L.camara* showed less density compared these two major IAPS with 334 stems ha^{-1}. Maximum abundance was showed by *C. odorata* (97.1), followed by *S.spectabilis* (27.8). *L. camara* showed less abundamce (6.76). The highest frequency among tree species in plantation was shown by *Tectona grandis* (62.2), which means that 62.2 % of the total sample plots had *Tectona grandis. C. odorata* had highest frequency in the plantation (87.06) followed by *Mimosa pudica* (49.41) .The frequency of *L. camara* was 45.8%. *Glycosmis pentaphylla* is the native species that showed maximum frequency (62.3). Mimosa pudica and *Holarrhena pubescence* were other major species with higher frequencies viz. 49 and 36 respectively. The least frequency was shown by *Alstonia scholaris, Crassocephalum crepidioides, Uraria rufescens, Butea monosperma* and *Mimusops elengi.*

The highest frequency in *Vayal* was shown by *C. odorata* (3.12.9) and *Arundinella leptochloa* (83.5). *L.camara* showed a frequency of 37.6 which is comparatively less than *C.odorata* (Table 12). *S.spectabilis* had minimum in frequency (4.7). The lowest frequency was shown *by Saccioleps indica, Mitracarpus hirtus, Dipteracanthus postratus, Crassocephalum crepidioides, Dipteracanthus postratus* and *Melastoma malabathricum*. The most densely seen plant species in *Vayal* was *C. odorata* (7761 stems ha^{-1}) followed by *Aruninella leptochola* (2923 stems ha^{-1}). The density of L.camara was 215 stems ha^{-1}. *Tectona grandis* showed highest density among tree species with 47 stems ha^{-1}. Density of *S.spectabilis* was 29 stems ha^{-1}. The most abundantly seen plant species in *Vayal* was *Arundinella leptochloa* (35). It was followed by *C. odorata* (24).

Table 10. Phytosociological analysis of vegetation in Natural forest

SI. No	Species	F	RF (%)	D (Individuals/h)	RD (%)	A
1	*Ageratum conyzoides*	10.59	1.28	130.59	1.60	12.33
2	*Albizia odoratissima*	3.53	0.43	3.53	0.04	1.00
3	*Alstonia scholaris*	2.35	0.29	3.53	0.04	1.50
4	*Anacolosa densiflora*	1.18	0.14	1.18	0.01	1.00
5	*Anisomeles malabarica*	1.18	0.14	11.76	0.14	10.00
6	*Annona squamosa*	3.53	0.43	3.53	0.04	1.00
7	*Anocolosa densiflora*	1.18	0.14	11.76	0.14	10.00
8	*Anogeissus latifolia*	4.71	0.57	4.71	0.06	1.00
9	*Antiaris toxicaria*	2.35	0.29	9.41	0.12	4.00
10	*Aporosa cardiosperma*	1.18	0.14	2.35	0.03	2.00

11	*Asclepias curassavica*	3.53	0.43	5.88	0.07	1.67
12	*Azadirachta indica*	2.35	0.29	5.88	0.07	2.50
13	*Baliospermum montanum*	2.35	0.29	2.35	0.03	1.00
14	*Barleria mysorensis*	1.18	0.14	3.53	0.04	3.00
15	*Bauhinia acuminata*	1.18	0.14	2.35	0.03	2.00
16	*Bauhinia malabarica*	4.71	0.57	5.88	0.07	1.25
17	*Bauhinia racemose*	2.35	0.29	5.88	0.07	2.50
18	*Blumea membranacea*	1.18	0.14	2.35	0.03	2.00
19	*Bombax ceiba*	5.88	0.71	14.12	0.17	2.40
20	*Briedelia retusa*	7.06	0.86	10.59	0.13	1.50
21	*Butea monosperma*	1.18	0.14	5.88	0.07	5.00
22	*Caesalpinia mimosoides*	2.35	0.29	2.35	0.03	1.00
23	*Calotropis floribunda*	1.18	0.14	1.18	0.01	1.00
24	*Calotropis gigantea*	1.18	0.14	1.18	0.01	1.00
25	*Canscor diffusa*	1.18	0.14	1.18	0.01	1.00
26	*Carallia brachiata*	5.88	0.71	82.35	1.01	14.00
27	*Cardiospermum halicacabum*	2.35	0.29	5.88	0.07	2.50
28	*Carmona retusa*	3.53	0.43	5.88	0.07	1.67
29	*Caryota urens*	2.35	0.29	10.59	0.13	4.50
30	*Cassia fistula*	32.94	3.99	94.12	1.16	2.86
31	*Catunaregam spinosa*	18.82	2.28	62.35	0.77	3.31
32	*Centella asiatica*	1.18	0.14	1.18	0.01	1.00
33	*Chamaecrista absus*	2.35	0.29	7.06	0.09	3.00
34	*Chromolaena odorata*	71.76	8.70	3734.12	45.85	52.03
35	*Cinnamomum verum*	4.71	0.57	11.76	0.14	2.50
36	*Cipadessa baccifera*	45.88	5.56	162.35	1.99	3.54
37	*Clerodendrum infortunatum*	1.18	0.14	1.18	0.01	1.00
38	*Cosmostigma neilgherrensis*	1.18	0.14	7.06	0.09	6.00
39	*Curculigo orchioides*	5.88	0.71	37.65	0.46	6.40
40	*Curcuma neilgherrensis*	10.59	1.28	35.29	0.43	3.33

41	*Cyclea peltata*	25.88	3.14	40.00	0.49	1.55
42	*Dalbergia lanceolaria*	1.18	0.14	1.18	0.01	1.00
43	*Dalbergia latifolia*	1.18	0.14	1.18	0.01	1.00
44	*Dendrocalamus strictus*	31.76	3.85	89.41	1.10	2.81
45	*Desmodium gangetium*	5.88	0.71	41.18	0.51	7.00
46	*Desmodium heterocarpon*	3.53	0.43	7.06	0.09	2.00
47	*Desmodium laxiflorum*	1.18	0.14	8.24	0.10	7.00
48	*Desmodium pulchellum*	1.18	0.14	4.71	0.06	4.00
49	*Diospyros meanoxylon*	1.18	0.14	4.71	0.06	4.00
50	*Elaeagnus kologa*	4.71	0.57	4.71	0.06	1.00
51	*Elaeocarpus variabilis*	1.18	0.14	1.18	0.01	1.00
52	*Elephantopus scaber*	12.94	1.57	63.53	0.78	4.91
53	*Eleutheranthera ruderalis*	2.35	0.29	7.06	0.09	3.00
54	*Flacourtia indica*	4.71	0.57	4.71	0.06	1.00
55	*Glycosmis pentaphylla*	38.82	4.71	472.94	5.81	12.18
56	*Gmelina arborea*	1.18	0.14	1.18	0.01	1.00
57	*Grewia tiliifolia*	2.35	0.29	2.35	0.03	1.00
58	*Haldina cordifolia*	2.35	0.29	2.35	0.03	1.00
59	*Helicteres isora*	23.53	2.85	56.47	0.69	2.40
60	*Hemidesmus indicus*	21.18	2.57	56.47	0.69	2.67
61	*Holptelea integrifolia*	1.18	0.14	2.35	0.03	2.00
62	*Hydnocarpus pentandra*	2.35	0.29	4.71	0.06	2.00
63	*Hyptis suaveolens*	2.35	0.29	4.71	0.06	2.00
64	*Imperata cylindrica*	1.18	0.14	3.53	0.04	3.00
65	*Kydia calycina*	3.53	0.43	96.47	1.18	27.33
66	*Lagerstroemia microcarpa*	4.71	0.57	7.06	0.09	1.50
67	*Lannea coromandilica*	2.35	0.29	1.18	0.01	1.00
68	*Lantana camara*	55.29	6.70	1061.18	13.03	19.19
69	*Lepidagathis incurva*	1.18	0.14	1.18	0.01	1.00
70	*Leucas aspera*	2.35	0.29	5.88	0.07	2.50

71	*Lindernia crutacea*	4.71	0.57	7.06	0.09	1.50
72	*Macaranga peltata*	1.18	0.14	5.88	0.07	5.00
73	*Mallotus philippensis*	1.18	0.14	3.53	0.04	3.00
74	*Mangifera indica*	2.35	0.29	3.53	0.04	1.50
75	*Melastoma malabatricum*	2.35	0.29	2.35	0.03	1.00
76	*Melia dubia*	1.18	0.14	1.18	0.01	1.00
77	*Mimosa diplotricha*	1.18	0.14	4.71	0.06	4.00
78	*Mimosa pudica*	38.82	4.71	217.65	2.67	5.61
79	*Mitracarpus hirtus*	1.18	0.14	21.18	0.26	18.00
80	*Mucuna pruriens*	1.18	0.14	1.18	0.01	1.00
81	*Narengi crenulata*	2.35	0.29	5.88	0.07	2.50
82	*Neolamarckia cadamba*	4.71	0.57	0.00	0.00	0.00
83	*Ocimum tenuiflorum*	10.59	1.28	251.76	3.09	23.78
84	*Olea dioica*	8.24	1.00	30.59	0.38	3.71
85	*Oroxylum indicum*	1.18	0.14	1.18	0.01	1.00
86	*Osbeckia aspera*	2.35	0.29	2.35	0.03	1.00
87	*Oscimum gratissimum*	2.35	0.29	14.12	0.17	6.00
88	*Persea macrantha*	4.71	0.57	18.82	0.23	4.00
89	*Phyllanthus emblica*	2.35	0.29	2.35	0.03	1.00
90	*Piper nigrum*	10.59	1.28	34.12	0.42	3.22
91	*Pongamia pinnata*	3.53	0.43	5.88	0.07	1.67
92	*Premna mollissima*	2.35	0.29	9.41	0.12	4.00
93	*Pterocarpus marsupium*	4.71	0.57	7.06	0.09	1.50
94	*Rauvolfia serpentina*	1.18	0.14	4.71	0.06	4.00
95	*Sapindus emarginatus*	5.88	0.71	7.06	0.09	1.20
96	*Schleichera oleosa*	4.71	0.57	14.12	0.17	3.00
97	*Schrebera swietenioides*	1.18	0.14	2.35	0.03	2.00
98	*Senna spectabilis*	18.82	2.28	414.12	5.08	22.00
99	*Senna tora*	3.53	0.43	30.59	0.38	2.33
100	*Shorea roxburghii*	1.18	0.14	3.53	0.04	3.00

90

101	*Sida acuta*	1.18	0.14	11.76	0.14	10.00
102	*Sida rhombifolia*	11.76	1.43	21.18	0.26	1.80
103	*Solanum aculeatissimum*	27.06	3.28	105.88	1.30	3.91
104	*Spathodia companulata*	1.18	0.14	1.18	0.01	1.00
105	*Streblus asper*	7.06	0.86	16.47	0.20	2.33
106	*Symplocos waynadense*	1.18	0.14	8.24	0.10	7.00
107	*Syzygium cumini*	20.00	2.43	84.71	1.04	4.24
108	*Tabernamontana alternifolia*	2.35	0.29	2.35	0.03	1.00
109	*Tamilnadia uliginosa*	3.53	0.43	28.24	0.35	8.00
110	*Tectona grandis*	12.94	1.57	42.35	0.52	3.27
111	*Terminalia bellirica*	2.35	0.29	5.88	0.07	2.50
112	*Terminalia elliptica*	4.71	0.57	16.47	0.20	3.50
113	*Terminalia paniculata*	9.41	1.14	22.35	0.27	2.38
114	*Trewia nudiflora*	8.24	1.00	31.76	0.39	3.86
115	*Vernonia cinerea*	1.18	0.14	4.71	0.06	4.00
116	*Vitex altisima*	2.35	0.29	18.82	0.23	8.00
117	*Wrightia tinctoria*	1.18	0.14	1.18	0.01	1.00
118	*Ziziphus oenoplia*	9.41	1.14	22.35	0.27	2.38
	Total	**824.7**	**100.0**	**8144.71**	**100.0**	**506.0**

F- Frequency, RF- relative frequency, D- density, RD- relative density, A- abundance

Table 11. Phytosociological analysis of vegetation in plantation

Sl. No	SPECIES	F	RF (%)	D (Individuals/h)	RD (%)	A
1	*Acacia sinuata*	1.18	0.15	2.35	0.02	2.00
2	*Acalypha paniculata*	7.06	0.88	11.76	0.09	1.67
3	*Ageratum conizoides*	2.35	0.29	3.53	0.03	1.50
4	*Ailanthus triphysa*	2.35	0.29	16.47	0.13	7.00
5	*Alstonia scholaris*	1.18	0.15	2.35	0.02	2.00
6	*Anisomeles malabarica*	4.71	0.59	21.18	0.17	4.50
7	*Asclepias curassavica*	4.71	0.59	9.41	0.07	2.00

8	*Asparagus racemosus*	1.18	0.15	2.35	0.02	2.00
9	*Axonopus compressus*	9.41	1.17	41.18	0.32	4.38
10	*Barleria mysorensis*	1.18	0.15	4.71	0.04	4.00
11	*Butea monosperma*	1.18	0.15	2.35	0.02	2.00
12	*Caesalpinia mimosoides*	2.35	0.29	4.71	0.04	2.00
13	*Caesalpinia sappan*	1.18	0.15	1.18	0.01	1.00
14	*Calycopteris floribunda*	3.53	0.44	4.71	0.04	1.33
15	*Casia fistula*	37.65	4.69	114.12	0.89	3.03
16	*Catunaregam spinosa*	2.35	0.29	2.35	0.02	1.00
17	*Chromolaena odorata*	87.06	10.85	8457.65	66.05	97.15
18	*Cinnamomum verum*	2.35	0.29	9.41	0.07	4.00
19	*Cipadessa baccifera*	14.12	1.76	37.65	0.29	2.67
20	*Citrus limon*	2.35	0.29	7.06	0.06	3.00
21	*Crassocephalum crepidioides*	1.18	0.15	1.18	0.01	1.00
22	*Curcuma neilgherrensis*	4.71	0.59	7.06	0.06	1.50
23	*Cyclea pelteta*	11.76	1.47	20.00	0.16	1.70
24	*Dalbergia latifolia*	11.76	1.47	28.24	0.22	2.40
25	*Dendrocalmus strictus*	25.88	3.23	108.24	0.85	4.18
26	*Desmodium gangeticum*	2.35	0.29	2.35	0.02	1.00
27	*desmodium laxifolium*	2.35	0.29	17.65	0.14	7.50
28	*Desmodium pulchellum*	2.35	0.29	2.35	0.02	1.00
29	*Desmodium triangulare*	7.06	0.88	10.59	0.08	1.50
30	*Elephantopus scaber*	10.59	1.32	35.29	0.28	3.33
31	*Eleutheranthera ruderali*	1.18	0.15	23.53	0.18	20.00
32	*Eucalyptus globulus*	1.18	0.15	10.59	0.08	9.00
33	*Glycosmis pentaphylla*	62.35	7.77	1030.59	8.05	16.53
34	*Gmelina arborea*	5.88	0.73	7.06	0.06	1.20
35	*Grewia tilifolia*	2.35	0.29	4.71	0.04	2.00
36	*Helicteres isora*	21.18	2.64	43.53	0.34	2.06
37	*Hemidesmus indicus V indicus*	9.41	1.17	16.47	0.13	1.75

38	*Hemidesmus pubescence*	36.47	4.55	132.94	1.04	3.65
39	*Holarrhena pubescens*	2.35	0.29	2.35	0.02	1.00
40	*Hydnocarpus pentandra*	3.53	0.44	3.53	0.03	1.00
41	*Hyptissua veolens*	2.35	0.29	9.41	0.07	4.00
42	*Lantana camara*	49.41	6.16	334.12	2.61	6.76
43	*Lepidagathis incurva*	42.35	5.28	236.47	1.85	5.58
44	*Mallotus tetracoccus*	4.71	0.59	4.71	0.04	1.00
45	*Melia dubia*	1.18	0.15	3.53	0.03	3.00
46	*Mikania micrantha*	1.18	0.15	2.35	0.02	2.00
47	*Mimosa pudica*	49.41	6.16	289.41	2.26	5.86
48	*Mimusops elengi*	1.18	0.15	1.18	0.01	1.00
49	*Mitracarpus hirtus*	1.18	0.15	1.18	0.01	1.00
50	*Naringi crenulata*	2.35	0.29	2.35	0.02	1.00
51	*Neolamarckia cadamba*	7.06	0.88	12.94	0.10	1.83
52	*Ocimum tenuiflorum*	27.06	3.37	220.00	1.72	8.13
53	*Olea dioica*	4.71	0.59	4.71	0.04	1.00
54	*Phyllanthus emblica*	1.18	0.15	1.18	0.01	1.00
55	*Plectranthus amboinicus*	5.88	0.73	17.65	0.14	3.00
56	*Pogostemon purpurascens*	3.53	0.44	70.59	0.55	20.00
57	*Pouzolzia zeylanica*	1.18	0.15	1.18	0.01	1.00
58	*Pterocarpus marsupium*	1.18	0.15	2.35	0.02	2.00
59	*schleichera oleosa*	1.18	0.15	1.18	0.01	1.00
60	*Senna spectabilis*	21.18	2.64	589.41	4.60	27.83
61	*Senna tora*	2.35	0.29	3.53	0.03	1.50
62	*Sida acuta*	5.88	0.73	9.41	0.07	1.60
63	*Sida alnifolia*	14.12	1.76	38.82	0.30	2.75
64	*Solanum aculeatissimum*	28.24	3.52	38.82	0.30	1.38
65	*Stachyphrynium jamaicensis*	1.18	0.15	23.53	0.18	20.00
66	*Sysigium cumini*	7.06	0.88	12.94	0.10	1.83
67	*Tamrindus indicus*	2.35	0.29	4.71	0.04	2.00

68	*Tectona grandis*	62.35	7.77	512.94	4.01	8.23
69	*Terminalia elliptica*	3.53	0.44	7.06	0.06	2.00
70	*Trewia nudiflora*	1.18	0.15	3.53	0.03	3.00
71	*Triumfetta rhomboidea*	1.18	0.15	23.53	0.18	20.00
72	*Tylophora indica*	1.18	0.15	1.18	0.01	1.00
73	*Uraria rufescens*	1.18	0.15	1.18	0.01	1.00
74	*Vateria indica*	3.53	0.44	3.53	0.03	1.00
75	*Vitex altissima*	2.35	0.29	2.35	0.02	1.00
76	*Ziziphus oenoplia*	20.00	2.49	50.59	0.40	2.53
	Total	**802.3**	**100.0**	**12805.88**	**100.0**	**400.33**

F- Frequency, RF- relative frequency, D- density, RD- relative density, A- abundance

Table 12. Phytosociological analysis of vegetation in *Vayal*

Sl. No	SPECIES	F	RF (%)	D (Individuals/ha)	RD (%)	A
1	*Ageratina adenophora*	14.12	1.45	109.41	0.75	7.75
2	*Ageratum conyzoides*	28.24	2.90	92.94	0.64	3.29
3	*Anogeissus latifolia*	11.76	1.21	17.65	0.12	1.50
4	*Apocopis mangalorensis*	14.12	1.45	23.53	0.16	1.67
5	*Artanema longifolium*	20.00	2.05	192.94	1.32	9.65
6	*Arundinella leptochloa*	83.53	8.56	2923.53	19.99	35.00
7	*Asclepias curassavica*	49.41	5.07	665.88	4.55	13.48
8	*Axonopus compressus*	24.71	2.53	224.71	1.54	9.10
9	*Baliospermum montanum*	3.53	0.36	5.88	0.04	1.67
10	*Bauhinia acuminata*	8.24	0.84	16.47	0.11	2.00
11	*Bauhinia malabarica*	5.88	0.60	16.47	0.11	2.80
12	*Biophytum reinwardtii*	3.53	0.36	15.29	0.10	4.33
13	*Butea monosperma*	11.76	1.21	165.88	1.13	14.10
14	*Calotrois giagantea*	3.53	0.36	9.41	0.06	2.67
15	*Carya arborea*	8.24	0.84	37.65	0.26	4.57

16	*Catunaregam spinosa*	5.88	0.60	17.65	0.12	3.00
17	*Centalla asiatica*	3.53	0.36	7.06	0.05	2.00
18	*Chromolaena odorata*	312.94	32.09	7761.18	53.06	24.80
19	*Cipadessa baccifera*	5.88	0.60	23.53	0.16	4.00
20	*Citrus lemon*	9.41	0.97	17.65	0.12	1.88
21	*Colocasia esculenta*	4.71	0.48	15.29	0.10	3.25
22	*Crassocephalum crepidioides*	1.18	0.12	14.12	0.10	12.00
23	*Crotalaria laburnifolia*	5.88	0.60	7.06	0.05	1.20
24	*Curcuma neilgherrensis*	4.71	0.48	23.53	0.16	5.00
25	*Cyperus pilosus*	7.06	0.72	20.00	0.14	2.83
26	*Dalbergia latifolia*	3.53	0.36	4.71	0.03	1.33
27	*Dendrocalamus strictus*	25.88	2.65	122.35	0.84	4.73
28	*Digitaria ciliaris*	3.53	0.36	12.94	0.09	3.67
29	*Dipteracanthus postratus*	1.18	0.12	2.35	0.02	2.00
30	*Elephantopus scaber*	2.35	0.24	11.76	0.08	5.00
31	*Eleutheranthera ruderalis*	3.53	0.36	20.00	0.14	5.67
32	*Eragrostis tenella*	3.53	0.36	4.71	0.03	1.33
33	*Flemingia strobilifera*	2.35	0.24	7.06	0.05	3.00
34	*Glycosmis pentaphylla*	21.18	2.17	74.12	0.51	3.50
35	*Grangea maderaspatana*	1.18	0.12	3.53	0.02	3.00
36	*Helitus isora*	2.35	0.24	5.88	0.04	2.50
37	*Hemidesmus indicus*	5.88	0.60	25.88	0.18	4.40
38	*Holoptelea integrifolia*	1.18	0.12	2.35	0.02	2.00
39	*Hygrophila schulli*	2.35	0.24	3.53	0.02	1.50
40	*Imperata cylindraca*	3.53	0.36	7.06	0.05	2.00
41	*Jansenella griffithiana*	18.82	1.93	658.82	4.50	35.00
42	*Justicia adhatoda*	2.35	0.24	3.53	0.02	1.50
43	*Kyllinga nemoralis*	2.35	0.24	2.35	0.02	1.00
44	*Lannea coromandlica*	2.35	0.24	3.53	0.02	1.50
45	*Lantana camara*	37.65	3.86	215.29	1.47	5.72

46	*Lecas aper*	2.35	0.24	2.35	0.02	1.00
47	*Lepidagasthis incurva*	11.76	1.21	164.71	1.13	14.00
48	*Melastoma malabathricum*	1.18	0.12	4.71	0.03	4.00
49	*Mimosa pudica*	36.47	3.74	331.76	2.27	9.10
50	*Mitracarpus hirtus*	1.18	0.12	2.35	0.02	2.00
51	*Mitragyna parvifolia*	1.18	0.12	3.53	0.02	3.00
52	*Neolamarckia cadamba*	4.71	0.48	15.29	0.10	3.25
53	*Ocimum tenuiflorum*	10.59	1.09	32.94	0.23	3.11
54	*Olea dioica*	1.18	0.12	11.76	0.08	10.00
55	*Oxalis corniculata*	1.18	0.12	4.71	0.03	4.00
56	*panicum trypheron*	2.35	0.24	29.41	0.20	12.50
57	*phylanthus emblica*	1.18	0.12	16.47	0.11	14.00
58	*plectranthus amboinicus*	2.35	0.24	17.65	0.12	7.50
59	*pongamia pinetta*	2.35	0.24	2.35	0.02	1.00
60	*pouzolzia zeylanica*	2.35	0.24	4.71	0.03	2.00
61	*Rhynchospora acorymbosa*	2.35	0.24	4.71	0.03	2.00
62	*Saccioleps indica*	1.18	0.12	2.35	0.02	2.00
63	*Schleichera oleosa*	1.18	0.12	1.18	0.01	1.00
64	*Senna spectabilis*	4.71	0.48	29.41	0.20	6.25
65	*Senna siamea*	1.18	0.12	2.35	0.02	2.00
66	*Senna tora*	4.71	0.48	37.65	0.26	8.00
67	*Sida acuta*	1.18	0.12	23.53	0.16	20.00
68	*Sida alnifolia*	1.18	0.12	2.35	0.02	2.00
69	*Sida rhombifolia*	7.06	0.72	21.18	0.14	3.00
70	*Solanam aculeatissimum*	34.12	3.50	112.94	0.77	3.31
71	*Syzigium cumini*	8.24	0.84	17.65	0.12	2.14
72	*Tabernamonta alternifolia*	1.18	0.12	1.18	0.01	1.00
73	*Tamilnadia uliginosa*	2.35	0.24	4.71	0.03	2.00
74	*Tectona grandis*	7.06	0.72	47.06	0.32	6.67
75	*Terminalia bellarica*	5.88	0.60	14.12	0.10	2.40

76	*Terminalia cuneata*	1.18	0.12	10.59	0.07	9.00
77	*Terminalia elliptica*	4.71	0.48	11.76	0.08	2.50
78	*Themeda triandra*	1.18	0.12	1.18	0.01	1.00
79	*Trewia nudiflora*	2.35	0.24	3.53	0.02	1.50
80	*Ziziphus oenoplia*	1.18	0.12	16.47	0.11	14.00
	Total	**975.29**	**100.0**	**14627.06**	**100.0**	**446.1**

F- frequency, RF- relative frequency, D- density, RD- relative density, A- abundance

The highest Simpson diversity index in NF was observed for control (0.94) plots and lowest was in 'L' plots (0.52) (Table 13). It is evident that the control plots were more diverse than any weed infested category areas in NF. Highest Berger-Parker dominance indices was obtained for 'LC' plots (0.81) and lowest in control plots (0.08). Maximum Margalef richness was seen in control plots (4.98) and lowest was in 'LS' plots (0.73). Pielou's equitability index was highest in 'control' plots (0.91), which imply that all individuals in 'control' plots are evenly distributed. Among the three IAPS, S and L plots had the limited species richness.

In plantation, highest Simpson diversity index was obtained in control plots (0.89), which states that control plots are the most diverse region in plantation (Table 14). The lowest Simpson diversity index was in 'L' plots (0.58). It is the control plots (0.31) have the lowest Berger-Parker dominance index. The 'CS' plots has the highest Berger-Parker index (0.70). Margalef richness index was highest in control plots (4.32) and 'LCS' plots (1.01) had the minimum richness. The control plots has the largest Pielou's equitability index (0.92). The lowest Pielou's equitability index was found in 'L' plots (0.71). Among the three IAPS, minimum species richness in plantation was in 'L' plots and was followed by C and S plots.

The highest Simpson diversity index in *Vayal* was seen in control plots (0.75) and the lowest was in 'LC' plots (052) (Table 15). Highest Berger-Parker dominance index was found in 'S' plots (0.71) and lowest was in control plots (0.34). It was the control plots that showed highest Margalef richness index value (3.51). The less richness was found with 'LC' plot (0.84). The control plot in *Vayal* has the highest Pielou's equitability index (0.58) which means that all individuals in *Vayal* were evenly distributed than other weed category areas. Among the three IAPS, minimum species richness and diversity was in L plots. It was followed by LC plots.

Table 13. Phytosociological analysis of weed category areas in NF

Weed category	Simpson Diversity Index	Berger-Parker Dominance Index	Margalef Richness Index	Pielou's Wiener Equitability Index
L	0.52	0.61	1.72	0.69
C	0.86	0.59	3.02	0.86
S	0.62	0.71	1.98	0.71
LC	0.81	0.81	2.24	0.88
CS	0.73	0.79	1.13	0.74
LS	0.78	0.67	0.73	0.81
LCS	0.70	0.69	2.12	0.72
CONTROL	0.94	0.08	4.98	0.91

Table 14. Phytosociological analysis of weed category areas in Plantation

Weed category	Simpson Diversity Index	Berger-Parker Dominance Index	Margalef Richness Index	Pielou's Wiener Equitability Index
L	0.58	0.64	2.86	0.71
C	0.73	0.58	3.19	0.87
S	0.74	0.60	3.18	0.89
LC	0.82	0.41	2.13	0.91
CS	0.78	0.70	1.23	0.90
LCS	0.71	0.42	1.01	0.85
CONTROL	0.89	0.31	4.32	0.92

98

Table 15. Phytosociological analysis of weed category areas in *Vayal*

Weed category	Simpson Diversity Index	Berger-Parker Dominance Index	Margalef Richness Index	Pielou's Wiener Equitability Index
L	0.44	0.76	1.10	0.43
C	0.63	0.54	1.28	0.51
S	0.69	0.71	0.91	0.42
LC	0.52	0.62	0.84	0.48
CONTROL	0.75	0.34	3.51	0.58

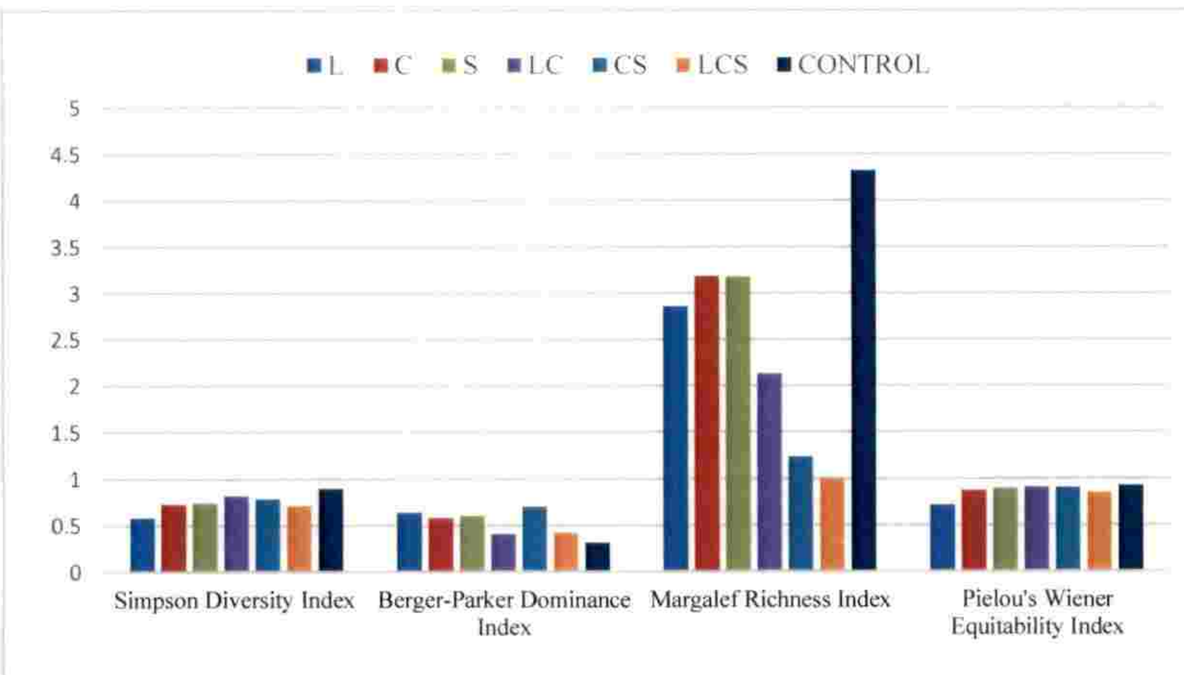


Figure 16. Phytosociological analysis of weed category area in NF

99

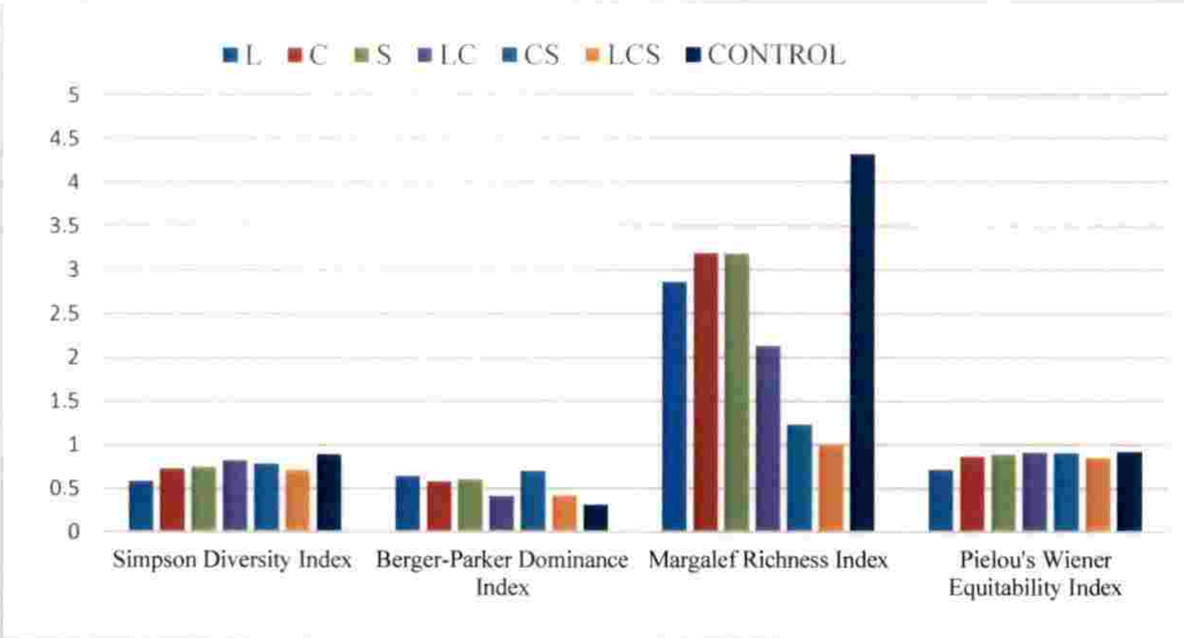


Figure 17. Phytosociological analysis of weed category area in Plantation

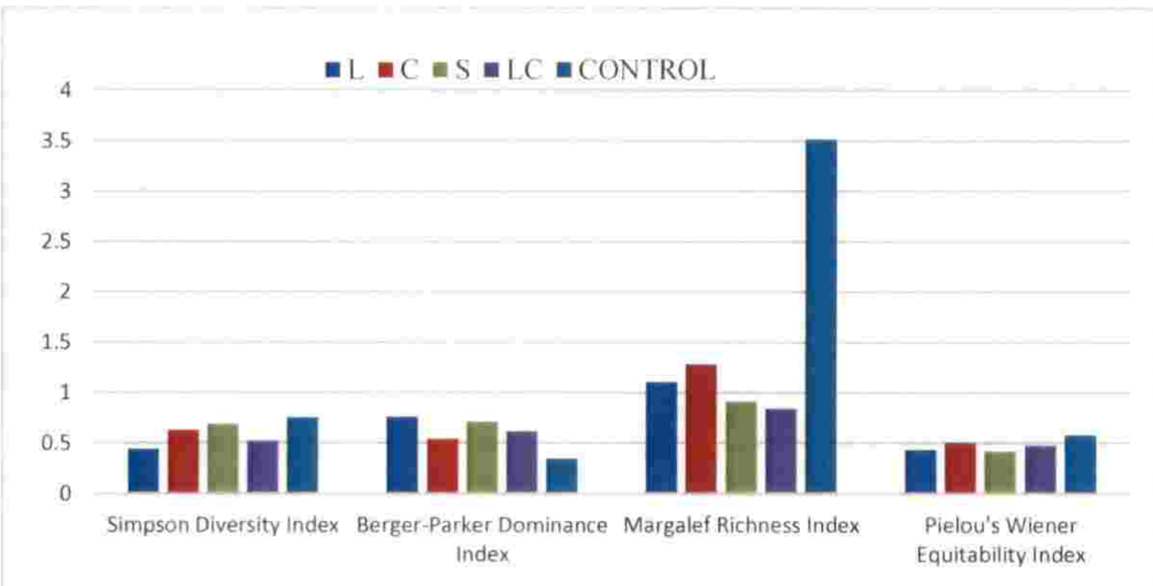


Figure 18. Phytosociological analysis of weed category area in *Vayal*

4.4.3 Relationship between percentage cover of IAPS and species richness of native species

Percentage cover of *L. camara, C. odorata and S. spectabilis* was regressed against the species richness of native species in each vegetation type. The models in each vegetation types were significant. Regression equations were made for each vegetation types (Table 16). Significance of regression coefficients were tested using ANOVA (<0.001). The models were h significant. All the three IAPS decreased the native species richness.

In NF, three IAPS caused about 0.33% variation by declining native species richness (Table 19). In plantation, this variation was 0.11% and in *Vayal*, it was 0.18 %. All the three IAPS negatively influenced the species richness of native plants (Fig. 19). From the Standardized Partial Regression Coefficients (SPRC) equation, it was found that in NF, *C. odorata* (0.29) had the firsthand influence on declining species richness of native species *L. camara* showed the SRPC (0.28) and *S. spectabilis* (0.22). All the three IAPS had almost similar influence on declining the species richness of NF. In plantation the *C.odorata* had less influence with SPRC (0.10). Both *L. camara* (0.19) and *C. odorata* (0.17) had almost similar influence on reducing the native species richness (Table 17). All the three IAPS negatively influenced the species richness of native plants (Fig. 20). In *Vayal C. odorata* had high SPRC value (0.41) and showed highest negative influence on species richness *L. camara* SPRC value (0.04) showed very less influence. *S.spectabilis* (0.19) started to invade the *Vayal* ecosystem. The impact *of L.camara* and *S.spectabilis* on native vegetation of *Vayal* is comparatively minimum than the effect of *C.odorata*.(Table 18). All the three IAPS showed negative relation with the species richness (Fig. 21).

Table 16. Multiple regression equation in Natural forest

Dependent variable	Independent variable	Equation	X_1	X_2	X_3	Intercept
Native species richness (Y)	Percentage cover of *C. odorata* (X_1)	$Y=50.82-0.43X_1-0.35X_2-0.27X_3$	-0.43	-0.35	-0.27	50.82
	Percentage cover of *L.camara* (X_2)					
	Percentage cover of *S. Spectabilis* (X_3)					

Table 17. Multiple regression equation in plantation

Dependent variable	Independent variable	Equation	X_1	X_2	X_3	Intercept
Native species richness (Y)	Percentage cover of C. *odorata* (X_1)	$Y= 47.79-0.24X_1-0.48X_2-0.34X_3$	-0.24	-0.48	-0.34	-47.79
	Percentage cover of *L.camara* (X_2)					
	Percentage cover of *S. Spectabilis* (X_3)					

Table 18. Multiple regression equation in *Vayal*

Dependent variable	Independent variable	Equation	X_1	X_2	X_3	Intercept
Native species richness (Y)	Percentage cover of *C.odorata* (X_1)	$Y= 89.56-0.46X_1-0.30X_2-0.55X_3$	-0.46	-0.30	-0.55	89.56
	Percentage cover of *L. camara* (X_2)					
	Percentage cover of *S. Spectabilis* (X_3)					

Table 19. Multiple regression equation to investigate the influence of IAPS on Species richness of native species in NF

Dependent variable	**Independent variable**	**Coefficient ± Standard error**	**SPRC**	***P***	R^2
Species richness	Percentage cover of *C.odorata*	−0.43 ± 0.09	-0.29	<0.001	0.33
	Percentage cover of *L. camara*	− 0.35 ± 0.08	-0.28	<0.001	
	Percentage cover of *S. spectabilis*	− 0.27 ± 0.07	-0.22	<0.001	

Table 20. Multiple regression equation to investigate the influence of IAPS on Species richness of native species in Plantation

Dependent variable	**Independent variable**	**Coefficient ± Standard error**	**SPRC**	***P***	R^2
Species richness	Percentage cover of *C. odorata*	−0.24 ± 0.13	-0.10	<0.001	0.11
	Percentage cover of *L. camara*	−0.48 ± 0.20	-0.19	<0.001	
	Percentage cover of *S. spectabilis*	− 0.34 ± 0.15	-0.17	<0.001	

Table 21. Multiple regression equation to investigate the influence of IAPS on Species richness of native species in *Vayal*

Dependent variable	**Independent variable**	**Coefficient ± Standard error**	**SPRC**	***P***	R^2
Species richness	Percentage cover of *C. odorata*	−0.46 ± 0.11	0.41	<0.001	0.18
	Percentage cover of *L. camara*	−0.30 ± 0.1	-0.04	>0.001	
	Percentage cover of *S. spectabilis*	−0.55±1.7	-0.19	>0.001	

(SPRC: Standardized partial regression coefficient)

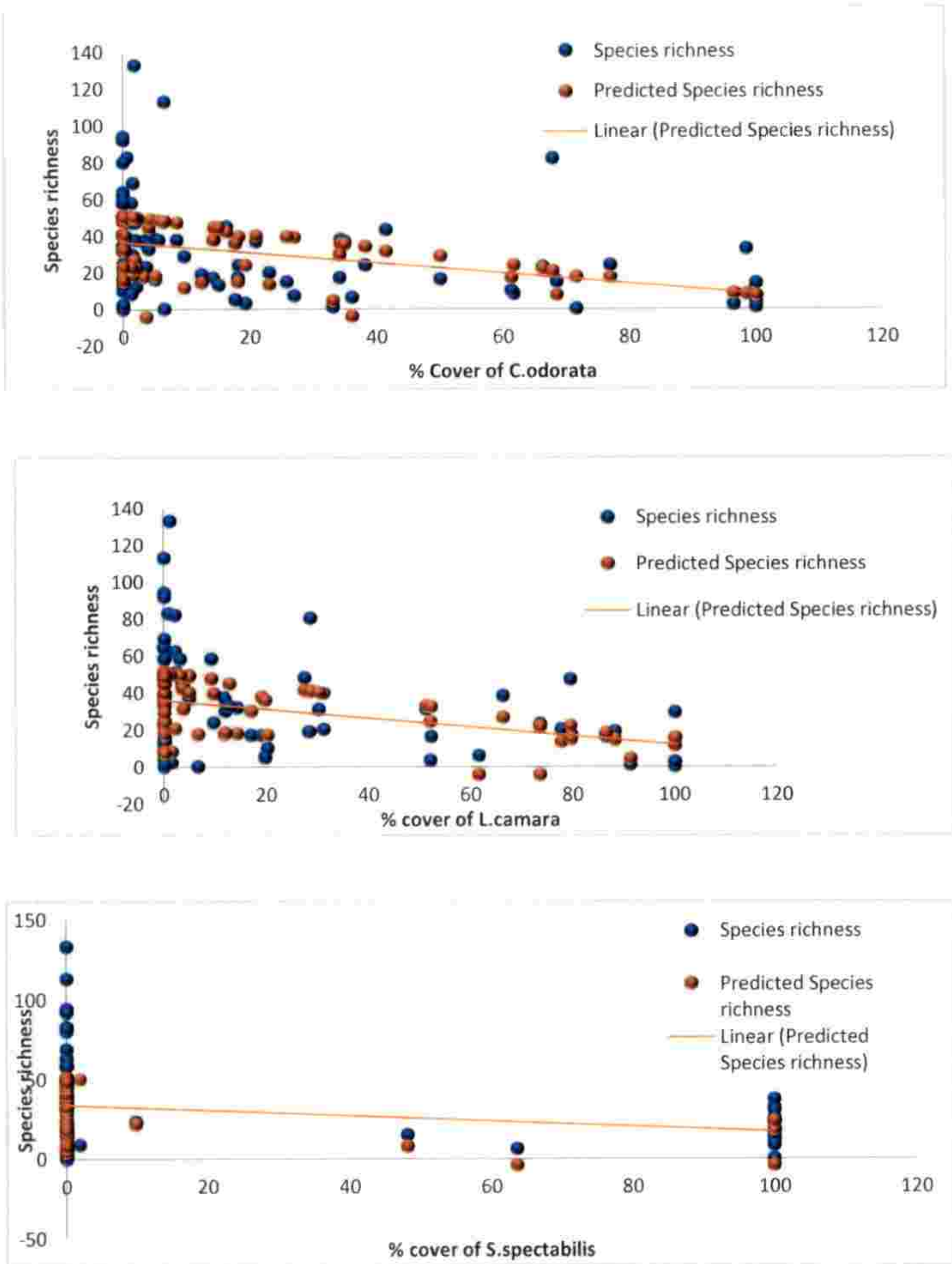
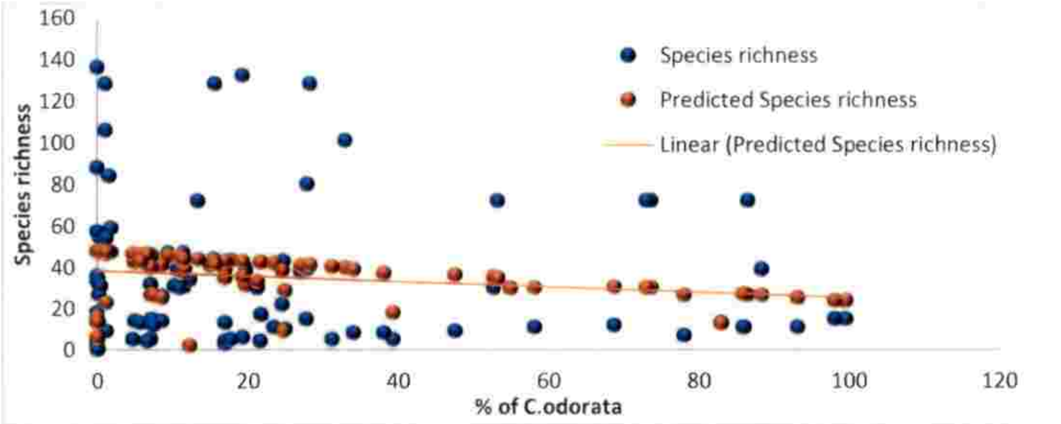
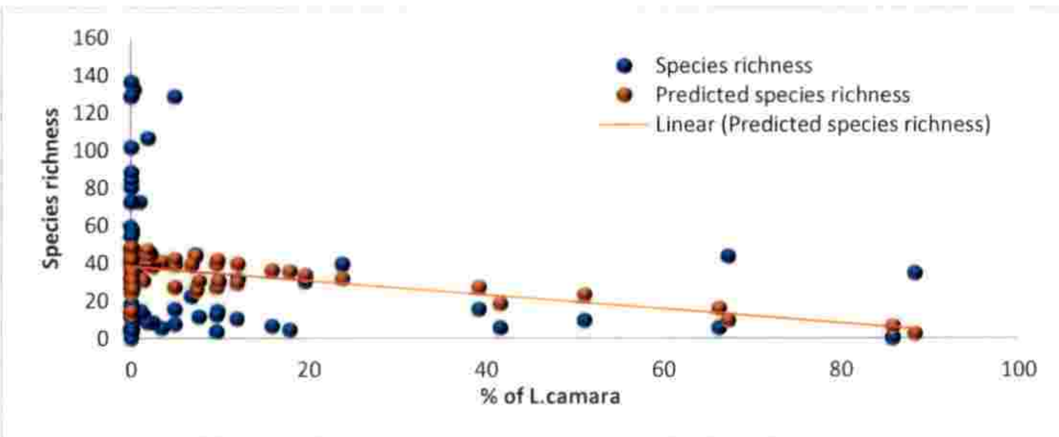


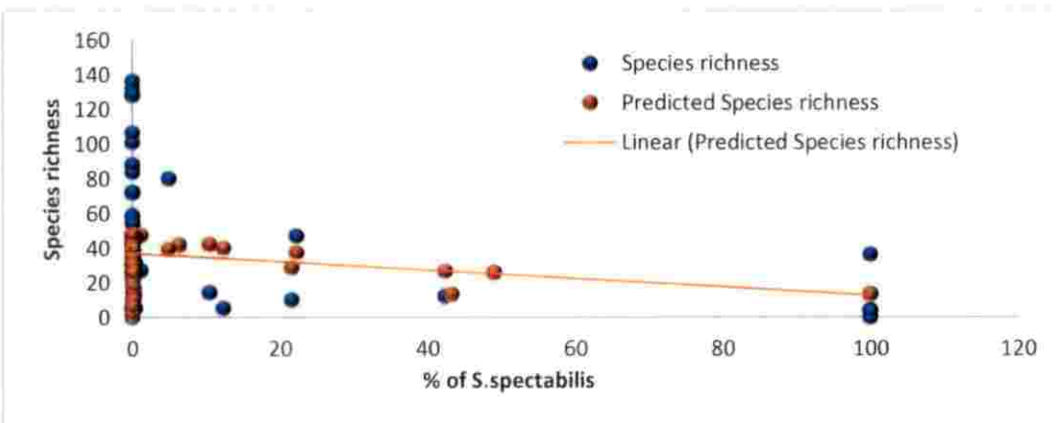
Figure 19. Actual and predicted relationship between species richness and percentage cover of *L.camara* (a) , *C.odorata* (b) and *S.spectabilis* (c) in NF



(a)



(b)



(c)

Figure 20. Actual and predicted relationship between species richness and percentage cover of *L.camara* (a), *C.odorata* (b) and *S.spectabilis* (c) in Plantation

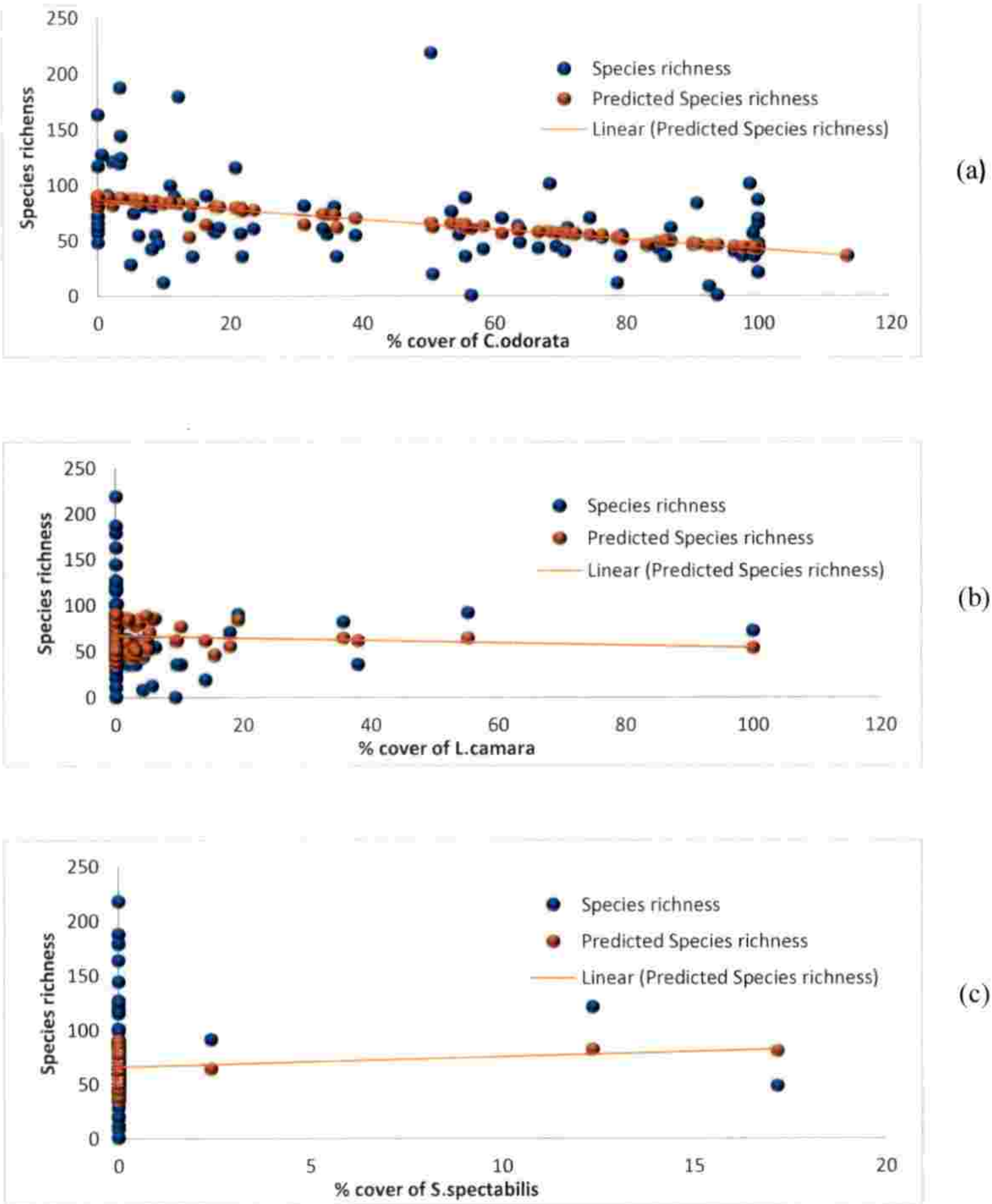


Figure 21. Actual and predicted relationship between species richness and percentage cover of *L.camara* (a) , *C.odorata* (b) and *S.spectabilis* (c) in *Vayal*

4.4.4 Correlation between Canopy Openness and percentage cover of IAPS

The correlation coefficient for canopy openness and percentage cover of IAPS in each vegetation type was calculated (Table 22). There was significant relationship between canopy openness and percentage cover of IAPS at 0.01 and 0.05 level (2-tailed). Each of the ecosystem a positive correlation between canopy openness and percentage cover was found. In Natural forest percentage cover *L. camara* had the highest correlation (0.527^{**}) with canopy openness and had highest distribution followed by *C. odorata* (0.339^{**}). The correlation between the combination of IAPS (*L. camara and C. odorata*) and canopy openness showed the value (0.690^{**}) which is the highest comparing to the individual species. In plantation percentage cover of *C. odorata* showed highest correlation (0.444^{**}) with canopy openness followed by *L. camara* (0.275^{*}). No correlation was found between canopy openness and percentage cover of individual IAPS in *Vayal*. The combination of *L. camara* and *C. odorata* showed correlation (0.217^{**}) which is very less.

Table 22. Correlation coefficient between canopy openness and percentage cover of IAPS in each vegetation type

Type	*Lantana*	*Chromolaena*	*Lantana + Chromolaena*
Natural forest	0.527^{**}	0.339^{**}	0.690^{**}
Plantation	0.275^{*}	0.444^{**}	0.563^{**}
Vayal	0.182	0.095	0.217^{**}

4.4.5 Native species composition of weed category sites

Native species composition of weed category sites was assessed using Principle Component Analysis (PCA) method, an unconstrained ordination technique was done to geometrically arrange the sites according to the species composition. Weed categories were classified into various sites.

In Natural forest the site 8 (control) had the highest native species composition (Table 23). The stress factor of this vegetation type was 1.04 which explains the suitability of arranging the sites geometrically. Almost all species identified in Natural forest are present in site 8 (Fig. 22). Site 1 and site 2 are very close and showed similarity in species composition, *Glycosmis pentaphyla* was the major native species found there. Site 1 and site 2 showed less ecological distance with site 8. These sites had comparatively less native species richness. Site 3, site 5, site 6 and site 7 are very close to each other with less ecological distance among them but comparing with site 8 these site had very less native species richness. *Kydia calycina, Solanum aculeatissimum* were the major species found here. Site 4 was arranged in an angle of 180degree with sight 8 showed that it was strongly negatively correlated with sight 8 and had very less native species richness. *Ocimum tenifloram* was the major species found in sight 4. The species rank was almost 120 in natural forest.

The stress value of plantation was 0.004 which was little less comparing to Natural forest. In plantation Site 8 (control) had the maximum native species composition (Table 23). In site 8 almost all species identified in plantation was found and *Tectona grandis* was found more (Fig. 23). Site 2, site 5 and site 4 showed more ecological distance with each other. Site 2 and site 4 showed almost 180 degree difference with site 8 and showed their high negative correlation and had less native species richness. *Glycosmis pentaphyla* was the major species in site 2 and *Mimosa pudica* found more in site 4. Site 1, site 3, site6 and site 7 were arranged closly and have less ecological distance with each other. In *Vayal* site 7 had highest native species composition and almost all species identified in *Vayal* was found in site7 (Table 24). The stress value found in *Vayal* was 0.004. Site 2 and site 4 were arranged far from site 7 and were almost 180 degree apart showed more ecological distance and had less native species richness. They were had strong negatively correlation (Fig. 24). *Arundinella leptochloa* was the major species found in site 2 and site 4. Site 1, site 3, site 5 and site 6 were arranged together and showed similarity with site 7.

Table 23. Site number and weed category areas in NF and Plantation

Site	1	2	3	4	5	6	7	8
Weed category	L	C	S	LC	CS	LS	LCS	Contr ol

Table 24. Site number and weed category areas in *Vayal*

Site	1	2	3	4	5	6	7
Weed category	L	C	S	LC	CS	LCS	Control

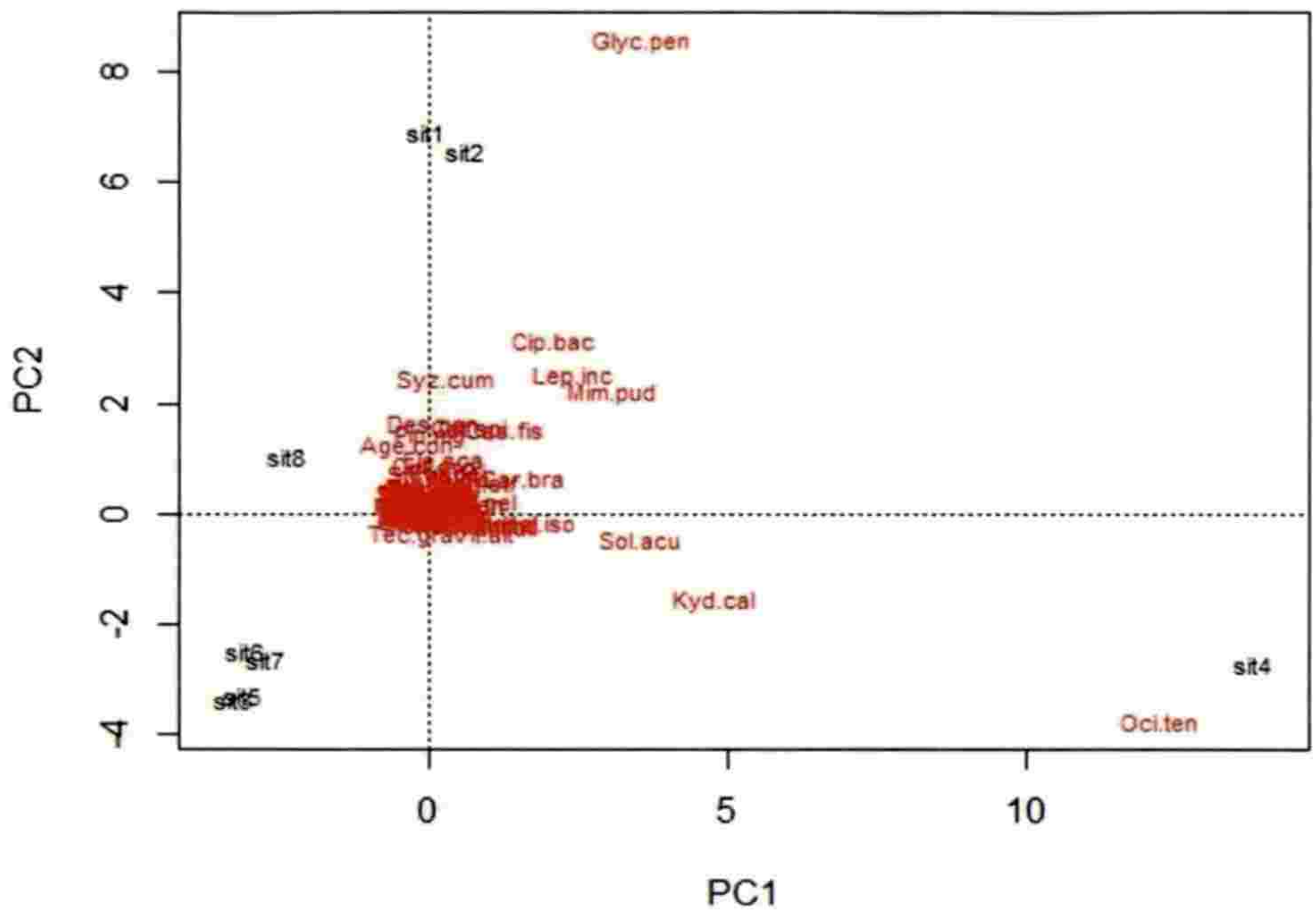


Figure 22. Principle component analysis (PCA) of Natural forest

109

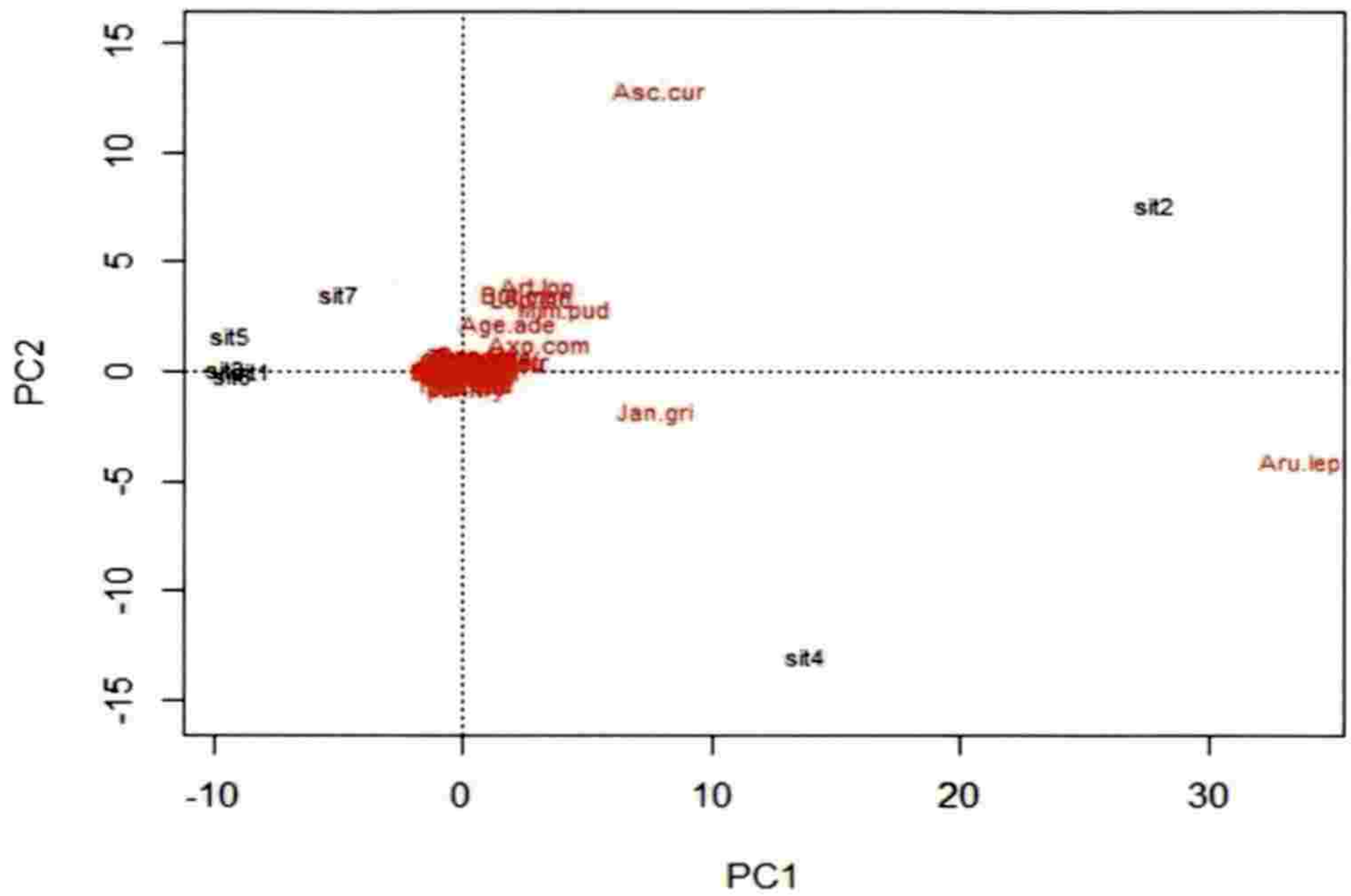


Figure 23. Principle component analysis (PCA) of Plantation

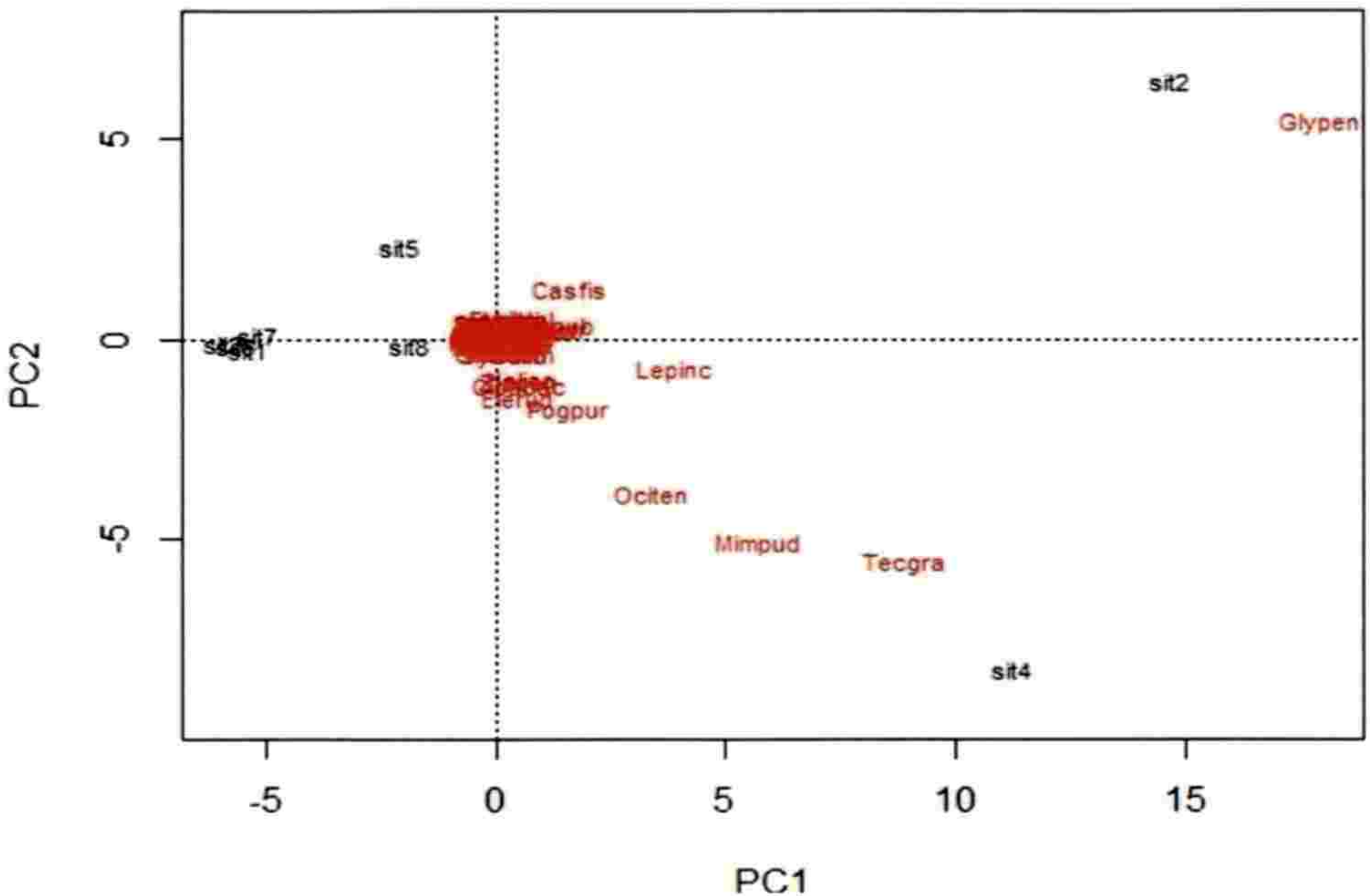


Figure 24. Principle component analysis (PCA) of *Vayal*

DISCUSSION

5. DISCUSSION

The results of the study conducted during 2018-2019 to understand the distribution characteristics and impacts of *L. camara*, *C. odorata* and *S. spectabilis* on the regeneration of other plant communities in the southern portion (WS I) of Wayanad WLS of Kerala is discussed below.

5.1. DISTRIBUTION OF IAPS

5.1.1. *Lantana camara*

Within India there are about 45,000 plants species (MoEF Annual report, 2012-13). According to (Mandal, 2011) 173 species of the Indian flora are invasive alien plants. *L. camara* was found spread all over the Tholpetty range of Wayand Wildlife Sanctuary. The distribution was high in Kaimaram, Thirulkunnu and Dasanghatta sections and was found less in Bavali section (Fig. 6). A study conducted in WS II part of Wayanad wildlife sanctuary by Vishnu (2017) had shown similar pattern of distribution of *L. camara* in WS I part also. According to Vishnu (2017) in WS II part plantations density of *L. camara* (322.35 ± 88.18). In WS I part plantation *L. camara* had density 334 ±1.02 (Table 4). In that study high invasion of *L. camara* was seen in Kurichiat RF (Kurichiat range), Rampur and Alathur RF in Sulthan bathery range and Edathara RF of Muthanga range.

Lantana camara is a pantropical weed from Verbenaceae family have a high potential to affect pasture and native forests negatively. It had shown its destructive impacts in more than 60 countries worldwide (Parsons and Cuthbertson, 2001). This plant which is a member of top 10 worst weeds of the world was introduced to India during 1800's from Sri Lanka as an ornamental plant, *Lantana* was introduced to National Botanical Garden in Calcutta (Ramesh *et al.*, 2017). It could thrive in diverse habitats, variety of soil types and generally grows best in open, unshaded situations

(Kohli *et al.,* 2006). Degraded land, pasture, edges of tropical and subtropical forests, warm temperate forests, and forests recovering from fire or logging could be a potential platform for the *Lantana* growth (Munir, 1996). It was observed that *L. camara* growing regions are having constant rainfall (>900 mm) or soil moisture (Van Oosterhout *et al.,* 2004). All these factors are favorable in WS I part Wayanad WLS and these may act as the reasons for the invasiveness of *L. camara*.

In disturbed natural forests, *Lantana* become the dominant understory vegetation. It competes with native pastures, it interferes with the foraging behavior of cattle, and also due to poisoning there are so many animal deaths (Babu *et al.,* 2009). The invasion of *Lantana* was known to be facilitated by the formation of forest openings due to fire, logging, and livestock grazing (Totland *et al.,* 2005), which may have concurrently led to native species loss and long-term persistence of dense *Lantana* thickets. In WS I of Wayanad wildlife sanctuary the recorded forest fire was minimum but the grazing livestock is high and could act as a reason for the spread of *Lantana* (Totland et al., 2005).

In a study conducted Singh *et al. (*1996) more than 13.2 million ha pasture lands in India are invaded by *Lantana*. Dobhal *et el.*, (2010) says that almost about 5 mha in Australia, 13 mha in India and 2 mha in South Africa is invaded by *Lantana*. A study by Ramaswami and Sukumar (2014) states that the establishment of native seedlings were affected by the invasive alien plants in the Western Ghats. Study by Muniappan *et al.,* (2002) warns that infestation of *Lantana* inside the Western Ghats was found to be a threat for native species and wildlife. *Lantana* is also capable to grow in teak plantations and invaded the majority of teak plantations in Tamil Nadu (Clarson and Sudha, 1997).WS I have 3840.5 hacters of teak plantation (Table3) and 7.5% of the studied area of plantation are invaded by *Lanatana* (Table 5)

5.1.2. *Chromolaena odorata*

C. odorata was the most invaded IAPS of WS I and it covered almost all regions very seriously. High invasion of *Chromolaena* was found in all the sections viz. Kaimaram, Thirulkunnu, Dasanghatta and Bavali (Fig. 7). Similar study conducted in WS II in 2017 shares the same pattern of distribution of *Chromolaena*. According to that study the borders of Kurichiat and Sulthan bathery ranges were free *Chromolaena* invasion. In Muthanga range, *Chromolaena* was less invaded in the borders of Mudumalai WLS but serious invasions were recorded in Mavinahalla and Noolpuzha RF of Muthanga range, Kallur and Rampur RF in Sulthanbathery range.

Chromolaena odorata, is an Asteraceae member which was introduced to many parts of the tropics. It is considered to be one of the most aggressive invasive plants which can take over any habitat with no time in tropical and sub-tropical areas (Witkowski and Wilson, 2001). *Chromolaena* have the ability to establish and distribute quickly and smother native vegetation (McFadyen and Skarratt, 1996).

This plant which is a member of top 10 worst weeds of the world (Ramesh *et al.*, 2017) was introduced to India the year 1845 as an ornamental plant to Calcutta. Raghubanshi (2005) states the swift spread of *Chromolaena* in Kerala started during 1942 and become invasive in southern India and it was from Calcutta. The study conducted by Ramalevha *et al.* (2018) has revealed that thousands of hectares of land in Vhembe District, of South Africa were infested by *Chromolaena odorata* with very limited time and effected the native species.

5.1.3. *Senna spectabilis*

Senna invasion was found to be serious in WS I part of Wayanad Wildlife Sanctuary. Out of the three major IAPS studied in the area *Senna* had shown maximum impact on the native species even with less percentage cover. It is now a major management challenge for forest managers all over the globe. Major invasion in WS I part was found towards the northern regions. Kaimaram section was the most effected region and Bavali section showed very less infestation. The study of impact of IAPS on native species conducted by Vishnu (2017) in WS II stated the similar results about *Senna*. In WS II of the sanctuary *Senna* was mainly distributed along the boundaries of Sulthan bathery and Muthanga ranges (Fig. 7) About 5.0 km^2 of area was highly invaded by *Senna*. From Muthanga station, *Senna* invasion was extended up to "Kakkapadam" in Muthanga range. *Senna* was also invaded on the both sides of National Highway from "Ponkuzhy" station to Kerala-Karnataka border.

Kerala Forests and Wildlife department states that as part Social forestry's shade tree planting program in 1986, seedlings of *S. spectabilis* were first raised in "Ponkuzhy" in Muthanga range. Seedlings were first planted in front of Muthanga forest station and along the sides of Muthanga range office. Fifteen seedlings were planted in Muthanga and some seedlings were also planted in "Meppadi" and "Aanappara" regions of Wayanad territorial division. Seven years after planting, first flowering of *Senna* appeared and the beautiful yellow flowers also attracted tourists. After 15 years of planting, these trees attained a GBH of 270 cm which proves the fast-growing character of *Senna*. Dispersing of seeds also happened swiftly and acquired an invasive character within a short time period. The results from the current study reveals that, the density of *Senna* was 414 individuals ha^{-1} in the NF, 589 individuals ha^{-1} in plantation and 34 individuals ha^{-1} in Vayal (Table 4). This could clearly tell about the potential regeneration of *Senna* under limited time in an area.

Mungatana and Ahimbisibwe (2010) stated that the the impact of *S. spectabilis* in the forest of Uganda was very serious as the native species were affected within less time. Wakibara and Mnaya (2002) had reported that that 225 ha (10% of whole NP) of forest land in Mahale mountains National park in Tanzania were invaded by *Senna*. *Senna* density in the Mahale NP was 586 trees ha^{-1} (Wakibara and Mnaya, 2002). In the present too, in WS I region, the density of *Senna* in Plantation were 589 individuals ha^{-1} (Table.4). Beyond Wayanad WLS, *Senna* displays high potential rapid growth in Sathyamangalam and suburban areas of Coimbatore (Sathyanarayana and Gnanasekharan, 2013).

5.2. IMPACT OF IAPS ON NATIVE PLANT DIVERSITY

The most dangerous characteristics shown by the Invasive alien species is homogenizing the world's fauna and flora on its way of extension across the world (Mooney and Hobbs, 2000). Study conducted by McKinney and Lockwood (1999), states that biotic homogenization contributed by the IAPS could suppress and replace the native biodiversity. It is evident from the current study that the presence of IAPS is altering the native plant diversity. The control plots (those plots without IAPS) in natural forest (NF) were observed to have more plant diversity than any other weed category areas (Table 13). Control plots (0.94) had the highest Simpson Index of Diversity (D) while the lowest values were recorded in 'L' plots (0.52). The low values of Simpson index of diversity analysed in' L' plot can state that *Lantana* is acting as a potential IAPS that alters the species diversity. *Senna* invaded areas (S, CS and LCS) also shows less Simpson Index of Diversity, that could be attributed to the invasion of *Senna*, which decreased the native plant diversity in WS I part. Fast growth and reproduction are the major traits of invasive alien plants which often make them spread swiftly in the invaded region. Heirro and Callaway (2003) says that to compete with native plants species the potential advantage is the account of allelopathy that makes them to out pass. In other words, they release toxic chemicals to the environment that in turn hamper the growth and establishment of native flora. The reduced species diversity here could probably be due to recruitment limitation mechanisms, which may include allelopathy and resource competition. The plots under C (0.86) recorded higher Simpson Index of Diversity, but the plots which had combinations *Senna* with *Chromolaena* noticed to have less diversity values (0.73). The plot which only had *Senna* (S) recorded lesser value (0.62). This clearly indicates that *S. spectabilis* invasion is perhaps more capable of limiting the development of many resident native species, causing reduced plant diversity, abundance and altered compositions as compared to *C. odorata.* In the study conducted in WS I Similar observations obtained but 'L' plots had higher Simpson index and *Lantana* wasn't a serious threat in that region to reduce the species diversity. Similar observation are found in the plantations also (Table 14). In control plots of plantations there were no dominant species, as the low Berger Parker Dominance values (0.31) is the evidence. The higher Equitability Index values (0.92) also points to the fact that all the species here were also equally distributed (Table 14).

Looking for the higher dominance index values it is found that *Lantana* (0.64), *Chromolaena* (0.58) and *Senna* (0.60) in plantation had higher values which clearly indicates their invasiveness and dominance elsewhere. Compared to *Chromolaena* areas, Lanatana invaded areas had lower species richness and unequal species distribution (Table 14). From these it can be inferred that in the studied plots located in the natural ecosystem, the impact of *Chromolaena* in resident plant diversity is low compared to *Lantana*. The study conducted in WSII states that *Chromolaena* is more dangerous than *Lantana* but in WS I *Lantana* found to be more dangerous. The density of *Lantana* was minimum in WSII were both are numerous in WSI. A study conducted by Van Oosterhout *et al*., (2004) could explain this situation as the species richness of native plants was compared with cover of *Lantana* which showed a strong negative non-linear relationship. The species richness of native species remained stable below 75% *Lantana* cover. But above the threshold level the species richness declined rapidly. This leads to the compositional change. The study concluded that at low rates of *Lantana* infestations, there was only little impact on the indigenous species. But the impact increased rapidly at further invasion of *Lantana*.

The species richness index value was observed to be least in the case of plots which have the combination of *Lantana* and *Senna* invaded areas (0.73) followed by

Lantana invaded plot (1.72) and *Senna* plot (1.98). Among the three IAPS, *Senna* invaded areas and *Lantana* invaded areas had the lowest Simpson diversity index and highest Dominance index values. This indicates that *S. spectabilis* and *C.odorata* are the most problematic IAPS among the three and is probably having the highest impact in the local plant diversity.

In Vayal, lowest Simpson index (D) was recorded in *Lantana* invaded plot and highest Dominance index value were recorded in *Senna* (S) invaded area (Table 15). In the study conducted in WS II there was no record regarding the presence of *Senna* in vayal ecosystem. Hence the major problematic IAPS in Vayal of WS II was *Chromolaena*. The Richness Index and Equitability Index value of S plots were 0.91 and 0.37 respectively; this is the lowest value in vayal. This shows that the species richness in *Lantana* invaded areas was low compared to control (3.51) and among them, some species are dominant. The Simpson Diversity Index and Dominance Index value of *Chromolaena* invaded areas were 0.63 and 0.54 respectively. These values confirm the fact that *Chromolaena* is the not that problematic IAPS as *Lantana* and *Senna* in vayal.

5.3. IMPACT ON NATIVE SPECIES RICHNESS

Among the weed category areas, control plots had the highest MSR (Mean Species Richness) (Table 8). Out of 140 plant species recorded from the WS I part of sanctuary, 113 plant species were present in control plots (weed free). However 21 species, viz, *Aporosa cardiosperma, Canscor diffusa, Canthium coromandelicum, Clerodendrum infortunatum, Elaeagnus kologa, Elaeocarpus tuberculatus, Flacourtia indica, Flemingia strobilifera, Hydnocarpus pentandra, Lindernia crustacean, Ludwigia peruviana, Mallotus tetracoccus, Osbeckia aspera, Piper nigrum, Premna mollissima, Rauvolfia serpentina, Streblus asper, Uraria rufescens* were seen only in control plots. They are more vulnerable to thrive in the weed infested areas. Their absence in the weed infested plots can be attributed to the better competitive ability and wide ecological tolerance of invasive species in recipient ecosystems (Gaertner *et al.*, 2009; Vila *et al.*, 2011).

On assessing the impact of three IAPS (*L. camara, C. odorata* and *S. spectabilis*) in the study area, the highest MSR in Natural forest was found in *Lantana* affected areas. A study conducted by Murali and Setty, (2001) says that in different ecosystems of Indian subcontinent, it was noted that the number of species was much lesser in *Chromolaena* affected plots and the regeneration of native species was seriously affected but *Lantana* shows comparatively less impact on the regeneration of the native species. Kumar *et al.* (2012) had observed that *C. odorata* is more invasive than *L. camara* as *Chromolaena* has the ability to change the soil pH, which in turn may prevent the regeneration of other species. But in Plantation and vayal , plots with *Chromolaena* showed more species richness than *Lantana* plots occured together, the MSR was lower in C plots compared to L plots. Sharma *et al.* (2005) compared the species richness of native plants with cover of *Lantana* and obtained a strong negative non-linear relationship. The species richness of native species remained stable below 75% *Lantana* cover. The study concluded that at low rates of *Lantana* infestations, there was only little impact on the indigenous species but the impact increased rapidly at further invasion of *Lantana*.

The species *Ageratum conyzoides, Anogeissus latifolia, Arundinella leptochloa, Biophytum reinwardtii var reinwardtii, Butea monosperma, Caesalpinia mimosoides, Calycopteris floribunda, Carallia brachiate, Cardiospermum halicacabum, Carmona retusa, Cassia fistula, Catunaregam spinosa, Crassocephalum crepidioides, Curculigo orchioides, Curcuma neilgherrensis, Cyperus pilosus, Dalbergia lanceolaria, Dalbergia latifolia, Desmodium heterocarpon, Desmodium laxiflorum, Desmodium pulchellum, Digitaria ciliaris, Diospyros melanoxylon, Elephantopus scaber, Eleutheranthera ruderalis, Eleutheranthera ruderalis, Eragrostis tenella, Glycosmis pentaphylla, Gmelina arborea, Grewia tiliifolia,* *Haldina cordifolia, Helicteres isora, Hyptis suaveolens, Jansenella griffithiana, Lagerstroemia microcarpa, Lagerstroemia speciosa, Lannea coromandelica, Mangifera indica, Mimosa pudica, Mimusops elengi, Mitracarpus hirtus, Naringi crenulata, Olea dioica, Panicum trypheron, Persea macrantha, Pogostemon purpurascens, Pongamia pinnata, Sacciolepis indica, Schleichera oleosa, Schrebera swietenioides, Senna tora, Shorea roxburghii, Sida acuta, Sida alnifolia, Solanum aculeatissimum, Spathodea campanulata, Sporobolus tenuissimus, Syzygium cumini var. cumini, Tabernamontana alternifolia, Tectona grandis, Terminalia cuneata, Terminalia elliptica, Themeda triandra, Ziziphus glabrata, Ziziphus oenoplia* were seen in both *Lantana* and *Chromolaena* invaded area. All these plant species perhaps have high tolerance to invasion by these two weed plants. At the same time, many plant species like *Aporosa cardiosperma, Bauhinia racemosa, Canthium coromandelicum, Careya arborea, Clerodendrum infortunatum, Cosmostigma racemosum, Elaeagnus kologa, Elaeocarpus tuberculatus, Elaeocarpus variabilis, Flacourtia indica, Flemingia strobilifera, Hydnocarpus pentandra, Lindernia crustacean, Ludwigia peruviana, Mallotus tetracoccus, Osbeckia aspera, Rauvolfia serpentine, Premna mollissima, Pterocarpus marsupium, Streblus asper, Vitex altissima, Ziziphus mauritiana* were conspicuously absent in the *Chromolaena* invaded area (Table 7).Though this study did not attempt to identify the mechanisms by which these IAPS causes recruitment limitation and subsequent species decline, there are published reports which suggest that this exclusion is driven by resource competition and allelopathy (Gentle and Duggin, 1997). At the same time, there is also a possibility that recruitment limitation could also be due to interference rather than exploitative interactions, for which more studies has to be conducted.

Potential competitive advantage on account of allelopathy makes them out pass native plant species. In other words, they release toxic chemicals to the environment that in turn hamper the growth and establishment of native flora. *Parthenium hysterophorus* is a potent allelopathic plant (Kohli and Rani, 1994). *Lantana camara* and *Ageratum conyzoides* are likewise reported as being strongly allelopathic (Ambika *et al.*, 2003; Kohli *et al.*, 2006). In fact, the allelopathic nature of many invasive alien plants forms the basis for the Novel Weapon hypothesis (Heirro and Callaway, 2003).

The least MSR was observed in plots were *Lantana* and *Senna* affected together in an area. There were only 13 native species in *Senna* invaded area (Table 7) and they are *Anogeissus latifolia, Carmona retusa, Cassia fistula, Crassocephalum crepidioides, Glycosmis pentaphylla, Haldina cordifolia, Helicteres isora, Lepidagathis incurve, Mimosa pudica, Terminalia elliptica* and *T. gradis*. All these plant species were recorded in all the seven vegetation types (Table 7). Thus, it can be concluded that, these plant species were perhaps more resistant to *Lantana*, *Chromolaena* and *Senna* invasion. It was found during the study that, in plots where *Senna* and *Chromolaena* occured together, the species richness decreased from 96 to 9 (Table 7). In plots where *Senna* occured with *Lantana* and *Chromolaena* species richness declined and plot with the combination of *Lantana* with *Senna* was more dangerous and the species richness decreased from 67 to 7, and had the least species richness. This probably indicates a dominating interference of *Senna* on the recruitment of native species and could be because of the impacts of its larger size, big and wider canopy, competitive reproductive ability, allelopathy and a broad, deeper root system.

5.4. POSSIBLE IMPACT SCENARIOS

Percentage cover of *Lantana*, *Chromolaena* and *Senna* affected the species richness of native species. Among the three IAPS, *C.odorata* had the primary impact on the species richness of native species in NF of WS I of sanctuary (Table 16). Kumar *et al.* (2012) found that, dense growth and multi stem forming nature of *Chromolaena* reduced the light penetration and this lead to the decline in native species richness. The allelopathic compounds present in *C. odorata* could have reduced the regeneration of native species (Gorshkov, 2004). After *Chromolaena*, it was *L. camara* which had an impact on native species. Murali and Setty (2014) observed that compared with

Chromolaena, *L. camara* may not suppress the growth of other species as they observed only a small decrease in species richness in *Lantana* invaded areas. In the present study the number of regenerating stems of native species (DBH at a range of 1 cm - 10 cm) in *Lantana* affected areas was higher than *Chromolaena* invaded area.

Increase in *L. camara* density in the three vegetation types decreased the native species richness (Fig. 20.b). The results obtained were similar to the variation found by de Groot *et al.*, 2012). At the same time when percentage cover of *Lantana* was plotted against species richness of native species, the actual/ observed species richness was almost closer to the predicted species richness and the results were more significant. Theoharides, (2007) found that *Lantana* invasion becomes severe only when the percentage cover (thickets) of *Lantana* is greater than a particular limit. In plantations *L. camara* had the primary affect on species richness (Table 17). Balaguru *et al.* (2016) studied the effect of *Chromolaena odorata* and *Lantana camara* on native plants in Palani Hill National Park (PHNP). About 12,568.3 ha and 2208.11 ha were infested by *Lantana* and *Chromolaena* respectively. The results revealed that *Chromolaena* shows lesser impact than *Lantana* in the PHNP. Fensham *et al.* (1994) found a negative correlation between plant species richness and *Lantana* density in a dry rainforest site in north Queensland and Gorchov *et al.* (2005) found that *Lantana*-invaded wet sclerophyll forest in southeastern Australia had substantially fewer plant species than reference non-invaded areas.

The maximum species richness was obtained when percentage of *L. camara* cover was minimum. For every 20% increase in *Lantana* cover, drastic negative correlation with native species was found from the WS I of the sanctuary. This pattern was similar in all the three vegetation types (Fig. 19). In the case of *Chromolaena*, maximum species richness was found at 0% of *C. odorata* cover. For every 20% increase in percentage cover of *Chromolaena* high negative correlation was found with native species was missing from the study area.

Contrary to the field observations, the results of regression analysis showed that *S. spectabilis* had the least impact on native plants. But in actual field observations (Table 7) the impact of *Senna* is very much evident. Only 20 plant species out of the 140 plant species identified from the sanctuary, were present in *Senna* invaded area. As already pointed out, *S. spectabilis* (Fig. 8), as of now, has invaded only limited areas of the WS I region. Compared with *Lantana* and *Chromolaena*, this invasion is considerably low. So, while sampling, this comparatively lower representation probably had masked the real impact of *Senna* on native plant species population. But going by the results of actual field observation, there is no doubt that if left uncontrolled, *Senna* will become a major threat in Wayanad WLS in the near future.

Canopy openness and percentage cover of IAPS showed positive correlation in entire WS I region (Table 22). The trees in this forest type have only less basal area and crown cover which increased the light intensity supports the weed growth (Balaguru *et al.* 2016). In Natural forest, *L.camara* showed more growth on increasing canopy openness. The forests recovering from fire or logging were seriously affected by *Lantana* (Parsons and Cuthbertson, 2001). *Lantana* invasion was greater under less shade conditions (60–80% open) (Ramaswami and Sukumar, 2014) . They also noticed that the *Lantana* invasion becomes severe in the forest gaps where there is more availability of light at ground level (Raizada *et al.,* 2008). In Africa by Totland *et al.* (2005) observed that the human interference and canopy openness increased the *Lantana* invasion.

While in plantation *C.odorata* was growing and have large percentage cover with increase in canopy openness (Table 22). According to Ramalevha *et al.* (2018) *Chromolaena* cover showed an inverse relationship with the canopy cover and height of native plants In a study conducted by Orapa *et al.* (2002) in Papua New Guinea open hill lands were completely affected by *Chromolaena*. In vayal ecosystem there wasn't any positive correlation showen by *L.camara* and *C.odorata* with canopy openness individually .The combination of *Lantana* and *cromolaena* showed positive correlation with openness but it was very minimum. In vayal the condition was different from NF and plantation. It is because continuous weeding programe is carried out so we could not figure out the relation between weed growth and canopy openness.

According to Surendra *et al.* (2013), the invasion of alien plant species may be affected by habitat disturbances and fire. So the negative happenings in the habitat in Wayanad WLS would have caused the variation in the observation. Negative associations between invader density and resident species diversity have been established for other significant woody IAPS including *Chrysanthemoides monilifera* ssp. rotundata (Mason and French, 2007) and *Cytisus scoparius* (Prevosto *et al.*, 2006).

The results of the current study were supporting the findings of Gooden *et al.* (2009). Similar observations were obtained for *C. odorata* and *S. spectabilis*. Allelochemicals present in *Lantana* decrease the vigour of native plants of region and results in ultimately poor productivity (Tylianakis *et al.*, 2008). The predicted species richness indicated that increase in percentage covers of *L. camara* gradually decreased the species richness of native species (Fig. 15).

IAPS will also severely affect the biodiversity of fauna. It will alter their foraging behavior and ultimately affect the food chain of the entire ecosystem. Invasive alien species such as *Lantana camara* makes them to find the carcass difficult and disturbs their food necessities (Samson *et al.*, 2016). *Lantana* makes difficult in forest operations by its sprawling growth habit. *Lantana* invasion reduced the fodder cover in pastures and grasslands. These changed the foraging behavior of cattle and wild herbivore's browsing area is reduced (Kohli *et al.*, 2006).

SUMMARY

SUMMARY

The study titled "Impact of invasive alien plants (IAP) on understorey vegetation in Wayanad Wildlife Sanctuary" was carried out to evaluate the distribution characteristics of selected invasive alien species viz. Lantana camara L., Senna spectabilis (DC.) H.S. Irwin and R.C. Barneby and Chromolaenaodorata (L.) R.M. King & H. Rob. in the selected ecosystems inside the Wayanad Wildlife Sanctuary (WLS). The study also aims to understand the impact of these invasive alien species on the regeneration of other plant communities. The results obtained from this study are summarized in this chapter.

1. L. camara was widely distributed over the WS I part of sanctuary. High invasion of L. camara was seen in the Kaimaram and Thirulkunnu sections. Dasanghatta section also had invasion but not like in Kaimaram and Thirulkunnu sections.

2. Higher densities of Chromolaena were found within the boundaries. Thirulkunnu section which share the boundary with Thirunelli RF also had invasions. Bavali section had comparatively less invasion.

3. S. spectabilis was seen in the Kaimaram section and higher density was seen near the boundary between Nagarhole TR and Kaimaram section.

4. Density (in 1 ha) of L. camara was 334.11 ± 1.02 (plantation), 1061.17 ± 2.75 (NF) and 215.29 ± 050 (Vayal). Density of C. odorata was 8457.64 ± 27.52 (plantation), 3734.11 ± 5.65 (NF) and 7761.17 ± 9.74 (Vayal). Density of S. spectabilis was 589.41± 2.67 (plantation), 414.11 ± 1.55 (NF) and 34.11± 0.21 (Vayal).

5. Percentage cover of C. odorata was highest in Vayal (46.19 ± 4.03(). In plantation and NF, the percentage cover was 24.58 ± 3.06 and 18.84 ± 3.09 respectively. The percentage cover of L. camara was highest in NF (19.46 ± 3.43). In plantation and Vayal , the percentage cover was 7.57 ± 1.96 and 4.43 ± 1.46 respectively. The percentage cover of S. spectabilis was highest in NF

(15.56 ± 3.85), lowest was in Vayal (0.37 ± .0.24) and in plantation it was (8.40 ± 2.68).

6. Based on the observation of invasive species infestation, the whole study area was divided into seven weed categories viz. L, C, S, LC, CS, LCS and Control (weed free area).

7. Among the seven weed category areas, the highest MSR (Mean Species Richness) was observed in control plots. It was followed by L (L. camara) plots and C (C. odorata) plots. The lowest MSR was observed in LS (L.camara and S. spectabilis) plots and CS (C. odorata and S. spectabilis). When Senna occurred together with Lantana and Chromolaena, the observed MSR was less, compared with other weed category areas.

8. The species richness of native species among habitat ($F2, 232 = 1.708$; $p>0.001$) and weed category areas ($F7, 232 = 13.93$; $p<0.001$) have significant variations. The interaction between vegetation type and weed category areas also showed significant variation ($F13, 232 = 4.01$ $p<0.001$).

9. About 0.33% variation was observed in native species richness due to the three IAPS in the regression model for NF. In plantation and Vayal the variation was 0.11% and 0.18% respectively. All the three IAPS negatively influenced the species richness of native plants. From the Standardized Partial Regression Coefficients (SPRC) equation it can be seen that in NF, C. odorata (0.29) had the primary influence on species richness of native species followed by L.camara (0.28) and S.spectabilis(0.22). In plantation both L. camara (0.19) and S.spectabilis (0.17) has almost similar influence on native species richness. In Vayal C. odorata (0.41) has highest influence on species richness followed by S.spectabilis (0.18).

10. Positive correlation between canopy openness and percentage cover of IAPS found and was significant at 0.01 and 0.05 level (2-tailed). In all type a positive correlation was found in natural forest L. camara had the highest correlation (.527**) followed by C.odorata (.339**). The correlation

between the combination of IAPS (L.camara and C.odorata) and canopy openness showed the value (.690**). In plantation C.odorata showed highest correlation coefficient (444**) followed by L. camara (.275*). No correlation was found between canopy openness and individual IAPS in Vayal.

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130

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133

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135

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147

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148

IMPACT OF INVASIVE ALIEN PLANTS ON UNDERSTOREY VEGETATION IN THOLPETTY RANGE OF WAYANAD WILDLIFE SANCTUARY

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ABSTRACT OF THE THESIS

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ABSTRACT

A study titled "Impact of invasive alien plants (IAP) on understorey vegetation in Tholpetty Range of Wayanad Wildlife Sanctuary" was undertaken to understand the distribution characteristics of selected invasive alien plant species (IAPS) viz., *Lantana camara* L., *Senna spectabilis* (DC.) H.S. Irwin and R.C. Barneby and *Chromolaena odorata* (L.) R.M. King & H. Robin in the three vegetation types (Plantation, NF, and *Vayal*) of WS I part of the WWLS. The additional objective was to assess the impact of these IAPS on the native plant communities in these vegetation types. In the WS I area, *L. camara* invasion was rampant, except in the southern regions. Higher invasion was seen in the Kaimaram and Thirulkunnu forest sections. *C. odorata* invaded all the four sections viz. Kaimaram, Dasanghatta, Thirulkunnu and Bavali. *S. spectabilis* invasion was heavy in the Kaimaram section near the boundary of Thirunelli RF, and in the boundaries between Nagarhole TR and Kaimaram section. In all the three vegetation types, the density of *Chromolaena* was high, while it was lowest for *Senna*. The density of *Chromolaena* in NF, Plantation and *Vayal* was respectively 3734.11 ± 5.65, 8457.64 ± 27.52 and 7761.17 ± 9.74 stems/ha. The density of *Lantana* in NF, plantation and *Vayal* was respectively 1061.17 ± 2.75,334.11 ± 1.02and 215.29 ± 0.50stems/ha. The density of *Senna* in NF, plantation and *Vayal* was 414.11 ± 1.55, 589 ± 2.67 and 34.11 ± 0.21stems/ha respectively. In the *Vayal*s, *Senna* invasion, though minimal, could be noticed. *Chromolaena* had the highest percentage cover in both plantation (24.58 ± 3.06) and *Vayal* (46.19 ± 4.03). In NF, *Lantana* (19.46± 3.43) had the highest percentage cover. In all the three vegetation types, *Chromolaena* had the highest frequency and abundance. Out of the total 140 plant species identified from the WS I region, number of species recorded in each weed category types like L, C, S, LC, CS, LS, LCS and Control were 67, 96, 20, 64, 9, 7, 14 and 113 respectively. Vis-a-vis the impacts of IAPS in NF, highest MSR (Mean Species Richness) was seen in Control (weed-free area), followed by L (*Lantana* invaded) and C (*Chromolaena* invaded) regions. The lowest MSR was in LCS (*Lantana*, *Chromolaena*, and *Senna* invaded) and LS (*Lantana* and *Senna* invaded) regions. In plantation, highest MSR was seen in Control (weed-free area) and the lowest in L (*Lantana* invaded) area. In *Vayal* too, highest MSR was observed in control, followed by C (*Chromolaena* invaded) and lowest in LC (*Lantana* and *Chromolaena* invaded) areas. All three IAPS negatively influenced the native species richness, although no specific declining trend in species richness could be observed. Among the three IAPS,

C. odorata had the biggest impact on the species richness of native species in both NF and *Vayal*. In the plantations, *L.camara* had the biggest impact on species richness. Canopy openness and percentage cover of IAPS were found to be positively correlated. In NF and *Vayal*, *Lantana* showed highest correlation with canopy openness, while in plantation, *Chromolaena* showed highest correlation with canopy openness. In plots where *Senna* and *Lantana* occurred together, plant species richness decreased from 67 to 7. Similarly, when *Senna* and *Chromolaena* came together, species richness dropped from 96 to 9. This probably indicates a dominating interference of *Senna* on the recruitment of native species which needs research attention. Left unmanaged, *Senna* will soon become a major "biological pollutant" of Wayanad WLS.