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

By

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(2016-17-005)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"IMPACT OF INVASIVE ALIEN PLANTS ON UNDERSTOREY VEGETATION IN 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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Introduction

INTRODUCTION

An alien species is an exotic or non-native species which was introduced by humans from one geographic region to another, intentionally or accidentally or through human agency for social or personal gain (Mandal, 2011). However, 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). After habitat destruction IAS considered as the second most threat to biodiversity (Pimentel *et al.,* 2000). Establishment and spread of IAS is a threat to habitats, ecosystems and other species. The world's worst 100 IAS include microorganisms, macro fungi, plants, amphibians, invertebrates, fishes, reptiles, birds and mammals (Lowe *et al.,* 2000). These invasive species are distributed in all ecosystems. Increase in the number of IAS and their wide extent across the world is homogenizing the world's fauna and flora (Mooney and Hobbs, 2000). The invasion of alien species is a mode of biological pollution. This is an important reason for global change and one of the main causes for species extinction (Drake *et al.,* 2016).

Invasive alien plant species changes the structure of the soil; affect the rate of decomposition, soil profile, nutrient content and moisture availability are affected (Lodge *et al.,* 2006). Invasive species becomes a serious barrier for conservation and sustainable use of biodiversity, with significant undesirable impacts on the goods and services provided by ecosystems. By preventing the establishment and growth of seedling, Invasive Alien Plant Species inhibit the recruitment of native species and modify the plant-pollinator interactions (Bjerknes *et al.,* 2007). These IAPS 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). Honnay *et al.* (2002) found that forest edges are the starting point of alien plant specie's invasions. The experiences of years of forest planning and management around Europe may be of considerable assistance in addressing the issue of invasive alien species (Sitzia *et al.,* 2016). Biological invasions now operate on a global scale and will undergo rapid increase in this century due to interaction with other changes such as increasing globalization and urbanization.

Wayanad Wildlife Sanctuary (WWLS) is located at the confluence of three biologically diverse and distinct regions – Nilgiri hills, Western Ghats and Deccan plateau. Due to its geographic location, WWLS faces considerable anthropogenic pressure but still harbor rich biodiversity and wild animal population. However, this protected area is also facing the threat of biological invasion 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. They are reported to impact and alter the native plant species composition in the sanctuary. Global Invasive Species Information Network (GISIN) reports that Lantana is one among the top ten invasive species in the world and is a problem in about 70 countries in the world (GISIN, 2012). In disturbed natural forests, 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 even though it is now threatening several ecosystems including Wayanad WLS.

Earlier research works on IAPS in Wayanad WLS studied only the distribution of weed species (Subramaniam *et al.,* 2001 and Sathyanarayana and

Gnanasekhara, 2013). But due to its aggressive behavior, these IAPS viz. *L. camara* *S. spectabilis* and *C. odorata* have 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 Wayanad WLS and also to evaluate their impact on native vegetation.

The specific objectives of the study includes

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 Wayanad Wildlife Sanctuary.
2. To understand the impact of these invasive alien species on the regeneration of other plant communities.

Review of literature

REVIEW OF LITERATURE

2.1 HISTORY OF INVASION

When man started to move from one point to another, other species also started to move accidentally or intentionally with them (Khuroo *et al.*, 2011). The Europeans journey across Africa and Asia during 15^{th} and 19^{th} century paved the way for introduction of alien species to all these regions. It was mainly for food and energy these species were introduced by Europeans to their colonies (Pysek *et al.*, 2012). Since the 16^{th} century, India had good trade relationship between African, Arabian and European countries. So many goods were imported and exported to these countries and thereby so many species were accidently introduced to India. The British, French, Portuguese and Spanish introduced large number of plants which were economically important to India. Many alien species were introduced into the interior natural forest by nomadic tribes as contaminants in food grains, packing materials, ballast water etc.

In India, several exotic plants were introduced intentionally for establishing botanical gardens, arboreta and also for ornamental 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 *et al.,* 2013). Among the 3,200 plants, about 992 were introduced from Caribbean and Latin America. As a result, the Garden became a source for spreading the alien plant species (APS). Some of the introduced plants like *Ipomoea carnea, Lantana camara, and Convolvulus arvensis* become invasive in a short time period. 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 countries and became invasive in a short time period. Eventually these species became a large threat to all ecosystems around the world.

Due to the increasing ecological and economic costs, the parties to the Convention on Biological Diversity 2010 held at Nagoya, Japan, adopted the Strategic Plan for Biodiversity 2011 - 2020 which specified that 'By 2020, invasive alien species 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 (Target 9 under the Strategic Goal B') (Goyal and Sharma, 2015).

2.2 THE INDIAN SCENARIO

India occupies only 2.4% of the total land area of the world and it contributes about 8% of world's total species diversity. The described number of species on earth is estimated to be 1.75 million (Meekins and McCarthy, 2001). India has extensive trade history with many countries through air, sea and land and these channels are the main reasons for the transfer of alien plants and animals from various geographical regions. Nowadays these movements are more rapid and the chance for being an invasive is higher. In India there are about 45,000 plants species (MoEF Annual report, 2012-13). Among that, 40% of the total flora is alien and 25% of these species becomes invasive (Raghubanshi *et al.,* 2005). A complete list of IAPS in India was prepared by Reddy *et al.* (2008). They identified 173 IAPS in India, which belongs to 117 genera in 44 families. The 74% of introduced species are native to South America and 11% was from tropical Africa. Compiling we can say that it was from neotropics that the 80% of the IAPS were introduced. Among the 173 IAPS, there are 151 herbaceous species, 14 shrubs, 5 climbers and 3 trees (Mandal, 2011). The Ministry of Environment and Forests, Govt. of India has collected and compiled the different invasive species of India. Sankaran and Suresh (2013), has given a comprehensive data regarding phenology, habitat, damage caused and management options of invasive plants in the forests of India.

The major IAPS which are seen in India include *Lantana camara, Chromolaena odorata, Mikania micrantha, Parthenium hysterophorus, Ageratum conyzoides, Mimosa diplotricha* var. *diplotricha, Acacia mearnsii, Agertaina adenophora, Cuscuta reflexa, Arundo donax, Leucaena leucocephala, Prosopis juliflora, Merremia peltata, Pteridium aquilinum, Sphagneticolaa trilobata and Imperata cylindrica* (Sankaran and Suresh, 2013*)*.

The diversity of IAPS in Himalayas was studied by Chandrasekar (2012). About 190 IAPS were recorded in the Himalayan region. Among these, the dicotyledons were 170 species in 40 families and mono-cotyledons 20 species by 7 families. By analyzing the invasive species it was noted that 18 species were introduced intentionally. Among the alien species, 73% was from America. Most dominant plant forms in Himalayan region are herbs (148 species). *Lantana camara* and *Ageratum conyzoides* were the major IAPS. Only 19 species were shrubs, 11 species grass and 4 were tree species.

2.3 KERALA SCENARIO

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 introduced from South America. Central America was the native of 6 species. Only 3 species were from Asia and rest of them was from Africa, Australia, and West Indies. Among the 38 species, 31 were introduced intentionally to the forests of Kerala.

2.4 REASONS FOR INVASIVENESS

One of the main characters of IAPS is their rapid growth and they attain maturity earlier than any other plants (Cordeiro *et al.,* 2004). Besides seed germination, many of the species reproduce vegetatively by stolons (*Eichhornia crassipes, Alternanthera philoxeroides*), bulbs (*Oxalis latifolia*), and rhizomes. Sometimes rooting may be present at the stem tips like in *Ipomoea carnea* and *Mikania micrantha*. Most of the IAPS are highly adapted to insect and wind pollinations. Because of lesser weight seeds, they could be easily dispersed by winds, birds and water. Allelopathic properties help these species to spread rapidly by competing with native plants (Joshi and Joshi, 2016). Invasive species like *L. camara* colonize quickly in open spaces. It alters normal ecological processes like plant succession. Thus the IAPS breaks the association between plants and animals. In dormant stages these plants have a discrete phenology for leafing which will help in the uptake of nutrients during dormancy. Usually these IAPS are not affected by diseases, parasites, natural enemies and they are not palatable to herbivores (Muthuramkumar *et al.,* 2006).

2.5 IMPACTS ON BIODIVERSITY

IUCN 2005 considered IAPS as the second largest threat to natural ecosystems after habitat destruction and deforestation (Tiwari *et al.*, 2005). IAPS transforms the species composition and structure ecosystems. It may directly affect the ecosystem through competition for resources or indirectly changes the pathway of nutrients in the cycle. This will affect the re-establishment of native species. McNeely *et al.,* 2001 conducted a study on the impact of IAPS on global scale. This study found that most of the IAPS will grow faster and reproduce rapidly than the native plants. Thus an alien plant species replaces the indigenous ones and becomes colonized in an area. IAPS decreased the water availability by degrading water catchment areas and freshwater ecosystem. Plants like *Lantana, Chromolaena* increased the chances of fire in forest areas. IAPS reduces the space, sunlight, water and nutrients that were needed for the native species. Soil structure, soil chemistry and the hydrological flows were also affected by the IAPS. They were also considered as biological polluters. By the invasion of alien plant species, about hundreds of flora were extinct from the world. In the case of flora it may be through competition and hybridization but considering the fauna neighboring species may be extinct due to predation, transmission of pathogens. African catfish is an example for this. IAPS has evolutionary, ecological and economic impacts.

Andrew and Vila (2011) conducted a study on the global literature review to evaluate the impacts of IAPS on the indigenous plants. The meta-analysis found that, there was a huge significant decline in the abundance and species richness of native plants after invasion. Invaded plots were 41% less abundant in native species than non-invaded plots and 30% less abundant than in removal plots. About 42% of species in world are on threatened or endangered list due to the alien species invasion.

Pimentel *et al.* (2000) studied the environment impact of IAPS in US. They found that most of the alien plants were intentionally introduced. In the last 40 years, the rate of introductions and the risks associated with the IAPS were increased enormously. The rapid growth of human population, transportation of goods and movement of people were the main reasons behind the increase in introduction of IAPS.

Parthenium has invaded about 14.25 mha of farm land in Karnataka within 75 years of introduction. Similarly *Prosopis juliflora* becomes invasive in 1.8% of total land area of India (Love *et al.*, 2009).

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

It is commonly known as Siam weed, which its origin is in S. America. This species was initially known as *Eupatorium odoratum* L by Linnaeus in 1759. In 1970 the name was changed to *Chromolaena odorata* King & Robinson. It is one of the serious terrestrial invasive plants in India, Central Africa, Australia and also in the Southeast parts of Asia (McFadyen, 2002). It was introduced as an ornamental plant to Calcutta, in the year 1845. During First World War (1924-25) this was spread to all parts of West Bengal and Orissa. It was from here this plant was spread to Kerala during 1942 and become invasive in southern India (Raghubanshi *et al.*, 2005). Then the *Chromolaena* spread to Southeast Asia, Western Pacific, Africa and northern Australia (Muniappan *et al.,* 2002). This plant species has the ability to grow in all climatic conditions and in all types of well-drained soil (Kriticos *et al.,* 2005). Sometimes it can also grow on soils that are having low fertility. Deaths may happens when the plant was eaten by domesticated animals (Aterrado and Bachiller, 2002). This species is becoming a serious problem in plantation crops, especially in teak, and it is also becoming a problem in disturbed forests. Due to its high allelopathic nature, it suppresses the neighboring vegetation. During dry seasons most of the stems will be dried, sometimes it will burn. In most of the cases the stumps will be unaffected by the fire, in such cases by the rainy season they show a rapid growth and they spread into all other area within a short time.

2.5.1.1 Global impact of Chromolaena

Ramalevha *et al.* (2018) has studied the impact of *Chromolaena odorata* on native species in Vhembe District, of South Africa. During the study period no new native species were identified from the study area. There was a strong relationship between *Chromolaena* and canopy cover and height of the native plants. 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. It found that Morobe, Manus, Sandaun, New Ireland, Oro and West New Britain were infested by *Chromolaena*. The major impact of Chromolaena was in young oil palm plantations in West New Britain. Reforestation programmes 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 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 a 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 seasonal fires were also increased due to the invasion of *Chromolaena* which damages the indigenous forest. Thus the *Chromolaena* replaced the forest vegetation easily. The invasion of the weed in forest gaps, suppressed the plant succession. 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.

2.5.1.2 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. During the study it was noted that the seeds of *Chromolaena* stuck on animal skins and 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 other native plant for nutrients, light, minerals and water. Thereby it suppressed the growth of surrounding vegetation and affected regeneration. It also decreased the grazing area of the herbivores. During dry season the dried stems of *Chromolaena* enhanced the forest fire. Sometimes it became toxic to wildlife as well as domestic animals.

2.5.1.3 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). These alien plants invasion threaten the integrity and biodiversity of Protected Areas (PAs). The results of the study revealed that *Lantana* have greater impact than *Chromolaena* in the PHNP. Lantana and *Chromolaena* infested about 12,568.3 ha and 2208.11 ha respectively. 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 dry mixed deciduous forest. The trees in this forest type have only less basal area and crown cover which increased the light intensity. These provided a suitable environment for the growth and spread of *Chromolaena*.

2.5.2 *Lantana camara* L.

Lantana camara (L.), it is also known as Spanish Flag. This species belongs to the family Verbenaceae, and native to the American tropics. *Lantana camara* is considered as one among the top 100 invasive species and it is one of the top 10 worst weeds of the world. It was in 1807 the *Lantana* was introduced by the Britishers in India. Because of its beautiful flowers they are introduced to East India Botanical Gardens in Calcutta (Ramesh *et al.,* 2017). Within a short period it was spread to all parts of the country. It is making greater challenge to the foresters and farmers. 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 large number of pollinators. They produce 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. Most of the varieties are allelopathic in nature, the chemicals released by the roots hinders the growth of nearby plants (Sharma *et al.,* 2005). 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)

2.5.2.1 Global impact of Lantana

Gooden *et al.* (2009) conducted a study on impact of Lantana on sclerophyll forest in southeastern Australia. The study found that when there was 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. 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 *Lantana* invasion was pervasive; it affects all the structural forms (i.e. trees, shrubs, herbs ferns and vines). But there were the losses of some significant species. The rate of species loss was comparatively greater for shrub and tree.

2.5.2.2 Impact of Lantana camara in India

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. Diversity of the plateau increased with decrease of lantana cover. About 26 species and 6825 individual seedlings were obtained at low lantana invasion area. There were 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 regeneration in highly invaded areas.

Impact of IAPS on forest areas based on the people's perspective in Hawalbag Block in Uttarakhand was studied by Kumar *et al.* (2016). People responded that 94.11% of alien plants invasion was due to the change in climatic conditions. 70.58% responded that the invasion was due to forest degradation and 52.98% said it was due to forest fires. There were reduction in productivity of herbs and fodder grasses due to *Lantana* invasion in the forest areas.

Dobhal *et al.* (2011) conducted a study on the impact of *Lantana* in riparian vegetation in Uttarakhand. 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. The *Lantana* invasion changed the distribution, composition, and growth (both in size and number) of indigenous species in the region. During the study it was found there was 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.

Kohli *et al.* (2006) studied the environmental threats and invasiveness of *Lantana* in India. The *Lantana* invasion reduced the biomass and density in the forest area of India. By replacing the native herbs and shrubs the weed became dominant in the forest understorey. The sprawling growth habit of *Lantana* makes difficult in forest operations. *Lantana* invasion reduced the fodder cover in pastures and grasslands. These changed the foraging behavior of cattle. In India, the *Lantana* invasions in sandalwood forests affected the quality of timber and caused the chances for spreading sandal spike disease.

Impact of *Lantana camara and Chromolaena odorata* on different ecosystems were studied by Murali and Setty (2001). 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.

2.5.2.3 Impact of Lantana camara in Western Ghats

Kumar *et al.* (2012) conducted a study on impact of *Lantana* on vegetation in Mudhumalai Tiger Reserve (TR) of Tamilnadu. Similar work was conducted in Africa by Totland *et al.* (2005). This study reveals that the human interference and canopy openness increased the *Lantana* invasion. The changes in elevation also effected the weed invasion in the TR. They reported that maximum grass availability was obtained in the weed free areas (54%) and only 19% grass was present in weed affected area. Species richness of grass species showed an inverse relationship with density of *Lantana*. It was found that initial growth of *Lantana* is faster than the native plants and they utilize the resources rapidly. *Lantana* invasion decreased the regeneration rate and growth of native plants. Due to the release of phytotoxins, it increased the mortality of native vegetation. The invasion of *Chromolaena odorata* is higher than that of *Lantana camara* in the Mudhumalai TR.

The fire history with the distribution of *Lantana camara* in the tropical dry forests of Mudumalai TR was studied by Ramaswami and Sukumar, (2014). High density of *Lantana* was seen in regions which were affected by fire once. Some areas in the 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). They also noticed that the *Lantana* invasion becomes severe when there is more availability of light at ground level (Raizada *et al.,* 2008).

Study conducted by Aravindhan and Rajendran (2014) in Velliangiri Hills, revealed that *Lantana* invasion leads to the degradation of native flora in the study area. Velliangiri Hills is a region in southern parts of Western Ghats. The high reproductive capacity, extraordinary growth, and absence of predator are the factors which favored spread of *Lantana* (Kohli *et al.,* 2006). The Large forest areas of Velliangiri Hills were cleared for agriculture and timber extraction. The study 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, Evolvulus alsinoides* were seen along with abundant *Lantana* infected areas.

2.5.3 *Senna spectabilis 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 200 species in the genus Senna

(Irwin and Barneby, 1982). 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 large number of seedlings. Now it has become an IPS in the forest areas and makes huge impact on the native species.

2.5.3.1 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 were suppressed by *S. spectabilis*. It was found that there was only little tree diversity in *S. spectabilis* dominated sites. This *S. spectabilis* has high alelopathic nature and suppresses the growth of neighboring native species except 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 the environmental services such as cropping systems, livestock grazing and recreational uses. Further it was noted that, these were the primary cause for 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.

2.5.4 Economic Loss

It is reported that huge economic loss is generated due to the invasion of alien species. It was estimated that in USA, an economic loss of about US$ 20 billon was occurred because of the invasion of animals and plants in each year (Hoffmann and Broadhurst, 2016). There was a yearly loss of $29.29 billion due to IAS in China. A study conducted in Benin says that due to the invasion of *Eichhornia crassipes* an amount of US$ 1,984 was lost every year. Based on a case study conducted in Philippines, there was a loss of 70,000 – 100,000 tons of paddy in the production sector due the IAPS in 1990. The IAS makes an economic loss of US$ 400 billion across the world in every year (Piment *et al.,* 2011)

Materials and methods

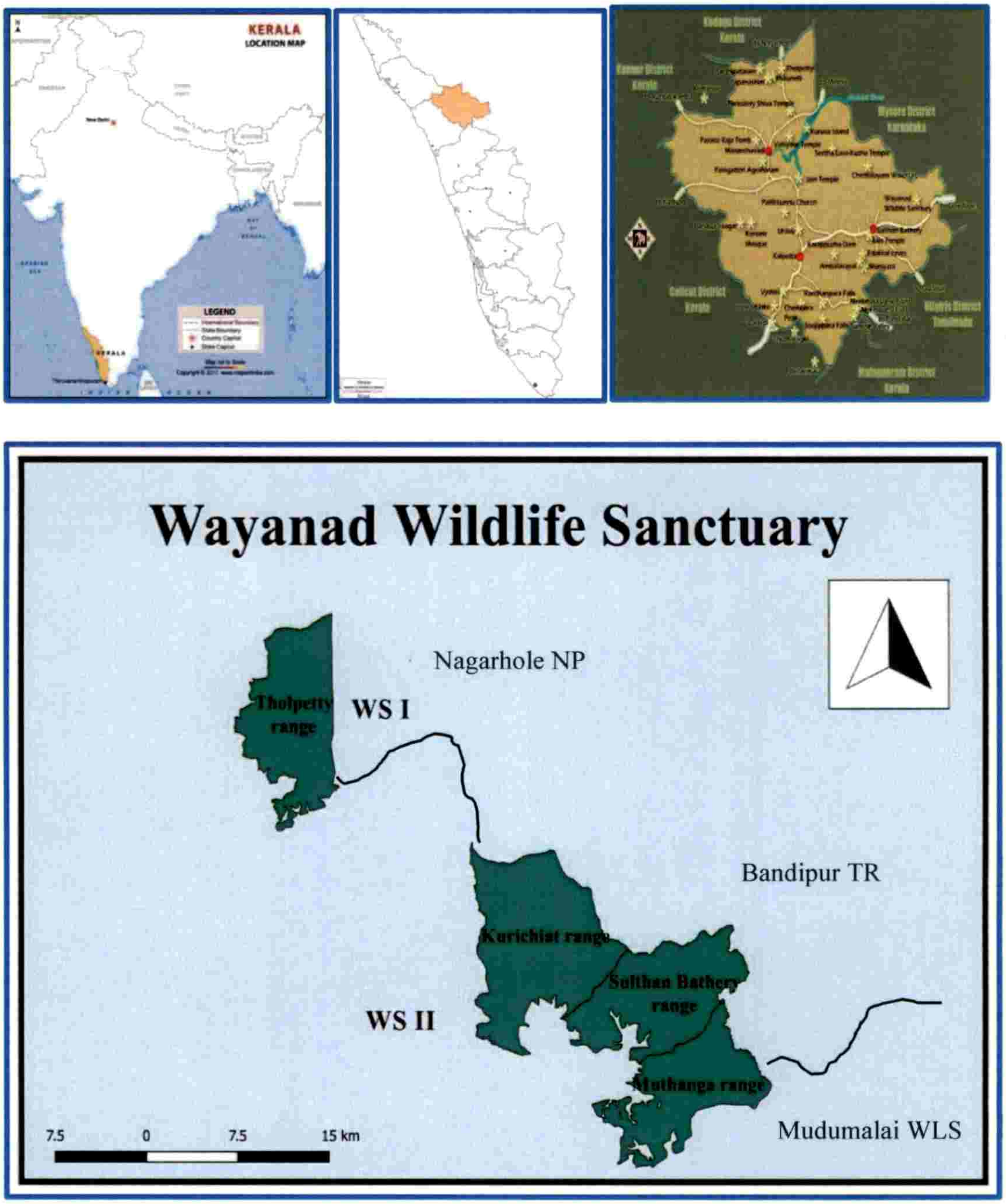
MATERIALS AND METHODS

The present study "Impact of invasive alien plants (IAP) on understorey vegetation in Wayanad Wildlife Sanctuary" was carried out is 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). The study also aims to understand the impact of these invasive alien species on the regeneration of other plant communities.

3.1 LOCATION

Wayanad is known as the land of paddy fields. It is situated in between an altitude of 700 to 1200 m above mean sea level. The district has an area of 2132 km^2. About 37% of total area is under forest cover (GOK, 2016). Wayanad Wildlife Sanctuary (WWLS) has an area of 344 km^2. It constitute 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. 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 Tamilnadu. 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 7th 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, the clear felling and regeneration of plantations were stopped. Then, these



(Source: GOK, 2012)

Figure 1. Location map of the study area

plantations were managed as part of habitat restoration, for their gradual transformation into diverse forest habitat.

3.2 CLIMATE

Maximum rainfall is obtained during the southwest monsoons. 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 that was revised by, 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 in 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 Rampur 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, Manimunda and Marode areas in Kallur RF, Arankunji area of Rampur RF, Kalladikolly - Vattavayal and Pulithookki - Pankalam areas of Mavinahalla RF.

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 'vayals' as they sustain grasses throughout the year. Because of waterlogged condition there are only little trees in vayals. These open grasslands are the main sites of herbivores foraging. Many of the vayals are given for lease to the farmers as part of Grow More Food Campaign. Both tribal and nontribal are doing cultivation in these vayals.

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 southern portion of the Sanctuary (WS-II). It constitutes three forest ranges, Muthanga, Kurichiat and Sulthan Bathery. The WS II lies within the geographical range of latitudes 11°35’ N and longitudes 76°13’ E.

Table 2. Area of plantation in Wayanad WLS

<table>
<tr><th>Sl.no.</th><th>Range</th><th>Reserve Forest</th><th>Extent (Ha)</th></tr>
<tr><td rowspan="3">1</td><td rowspan="3">Muthanga</td><td>Edathara RF</td><td rowspan="3">1466.897</td></tr>
<tr><td>Mavinahalla RF</td></tr>
<tr><td>Noolpuzha RF</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Sulthan Bathery</td><td>Alathur RF</td><td rowspan="3">1817.305</td></tr>
<tr><td>Kallur RF</td></tr>
<tr><td>Rampur RF</td></tr>
<tr><td rowspan="2">3</td><td rowspan="2">Kurichiat</td><td>Kuppady RF</td><td rowspan="2">370.045</td></tr>
<tr><td>Kurichiat RF</td></tr>
<tr><td rowspan="4">4</td><td rowspan="4">Tholpetty</td><td>Begur RF</td><td rowspan="4">3840.570</td></tr>
<tr><td>Edkode RF</td></tr>
<tr><td>Kartikulam RF</td></tr>
<tr><td>Kudrakkode RF</td></tr>
<tr><td></td><td>Total</td><td></td><td>7494.817</td></tr>
</table>

3.5 SAMPLING METHOD

3.5.1 Estimation of weed cover and density

The WS II 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 counted and recorded to calculate density. The density of weed species was converted to hectare.

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 II 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 seven weed categories (Table 7).

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

3.5.1 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 $= \sum_i [(\frac{ni}{N} \log_2 (\frac{ni}{N})]$

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

3.6.3 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. Multi linear regressions models were used to assess the relationship between percentage ground cover of IAPS and species richness (native herbs, shrubs, trees and climbers). 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).

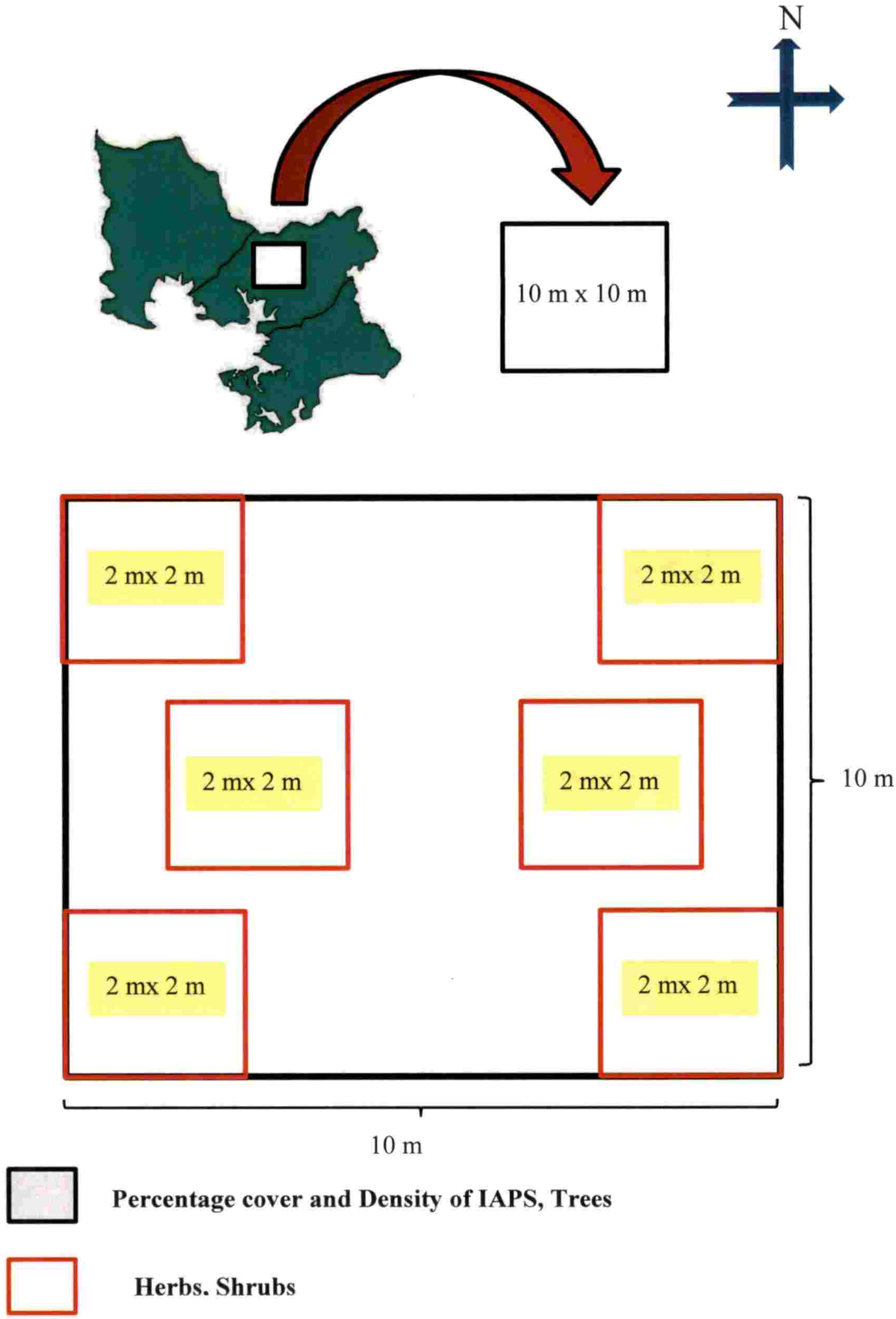


Figure 2. Diagrammatic representation of sampling

Results

RESULTS

The current study was conducted during 2017-2018 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 II) of Wayanad WLS of Kerala. The results obtained from the study are given below.

4.1 ESTIMATION OF WEED COVER AND DENSITY

The WS II part of sanctuary was divided into three vegetation zones viz. Natural forest (NF), Plantation and Vayal (Table 3). The deciduous forests were seen in south and west of Rampur Reserve Forest (RF) (Sulthan Bathery Range), most region of Kurichiat RF (Kurichiat Range) and south west of Mavinahalla RF (Muthanga Range) (Management plan, 2012-2022). Plantations were seen in Kurichiat and Kuppady RF (Kurichiat Range), Kallur and Rampur RF (Sulthan Bathery Range) and small portion of Mavinahalla RF (Muthanga Range).

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 (Plate 1a). 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 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. In most of the cases in the sanctuary *C. odorata* were seen as single non branching stem at a height of 0.5 m. The seeds are black to brown-gray color that is 4 mm long (Plate 1e).

(a)

(b)

(c)

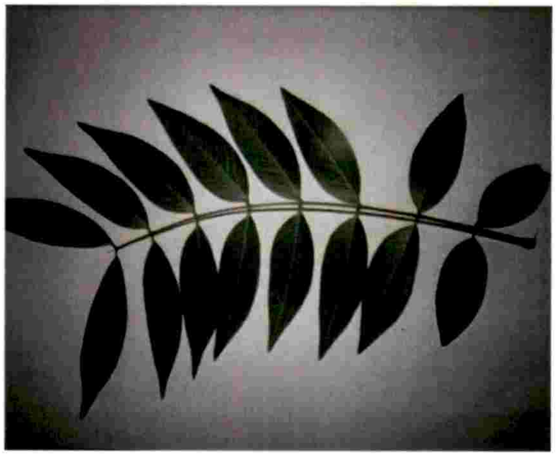
(d)

(e)

(f)

Plate 1. (a & b - Two color varieties of *L. camara* in Wayanad WLS, c - seeds of *L. camara,* d - *L. camara* thickets, e - flowers of *C. odorata,* f - *C. odorata* thickets

(a)



(b)

(c)

(d)

(e)

(f)

Plate 2. (a & b - leaves of *S. spectabilis*, c - flower, d - pod, e - *S. spectabilis* thickets, f - dried *S. spectabilis*)

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

S. spectabilis grows up to 15 m tall. Leaves are 18 – 30 cm long and the leaflets are 8 -14 pairs, ovate to lanceolate, obtuse at base, acute at apex and petioles are 2 -3 cm long (Plate 2b). Racemes are terminal or axillary, 6 -10 cm long, congested, corymbose panicles, few to many flowered; peduncles 2 ~ 3 cm long; pedicels 1.5 - 2.5 cm long; bracts narrowly ovate or lanceolate, acute or sub acuminate at apex, caducous.

4.1.4 Density of IAPS

Density of each weed species in all the three vegetation type were calculated (Table 4). *Chromolaena odorata* showed highest density in all the three vegetation types. There were 4943 stems of *C. odorata* in one hectare of plantation. It was followed by *L. camara* (322.3 stems ha^{-1}) and *S. spectabilis* (63.5 stems ha^{-1}). *Senna* infestation was too low compared to the density of *Chromolaena*. In NF there were 4996.4 stems of *C. odorata* in one hectare. The density of *L. camara* and *S. spectabilis* in NF were 85.42 and 49.74 stems ha^{-1} respectively. Maximum density of *C. odorata* (5810.5 stems ha^{-1}) was seen in vayal. The density of L. camara in vayal was 423 stems ha^{-1}. There was no *Senna* infestation in Vayal (Fig. 3).

4.1.5 Percentage covers of IAPS

The percentage of ground covered by IAPS was calculated in each vegetation type by measuring the crown area (Table 5). It was found that in NF about 14.2% of the total sampled area was invaded by *L. camara* and it is the most problematic invasive plant species in NF. *Senna spectabilis* (6.3%) is the least covered IAPS in NF. While coming to plantation, the *Lantana* infestation was only 7.5%. *Chromolaena odorata* invades 7.3% of sampled area in NF. In plantation, *L. camara* and *C. odorata* infested about 7.5% and 8.1% of the areas respectively. But *S. spectabilis* (2.6%) infestation in plantation was comparatively lower than other IAPS.

Out of the total sampled area there was no *S. spectabilis* infestation in vayal. In vayal, out of the total sampled area only 0.95% was invaded by *L. camara*. It was *C. odorata* which invades major portion of vayal (14.5%) (Fig. 4).

Table 3. Area covered by each vegetation type in the sanctuary

Vegetation type	**Area (km^2)**
Natural forest (NF)	191.43
Plantation	69.87
Vayal (Swamps/ low lying grassland)	5.53

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	4943.52 ± 1079.07	322.35 ± 88.18	63.5 ± 31.66
Natural forest (NF)	4996.47 ± 1484.42	85.42 ± 29.55	49.74 ± 23.93
Vayal (Swamps/ low lying grassland)	5810.59 ± 1262.43	423.53 ± 99.40	0

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

Vegetation type	**Percentage cover of IAPS (%)**		
	C. odorata	*L. camara*	*S. spectabilis*
Plantation	8.1 ± 1.1	7.5 ± 2.0	2.6 ± 1.6
Natural forest	7.3 ± 1.5	14.2 ± 2.8	6.3± 2.4
Vayal (Swamps/ low lying grassland)	14.5 ± 2.2	0.95 ± 0.3	0

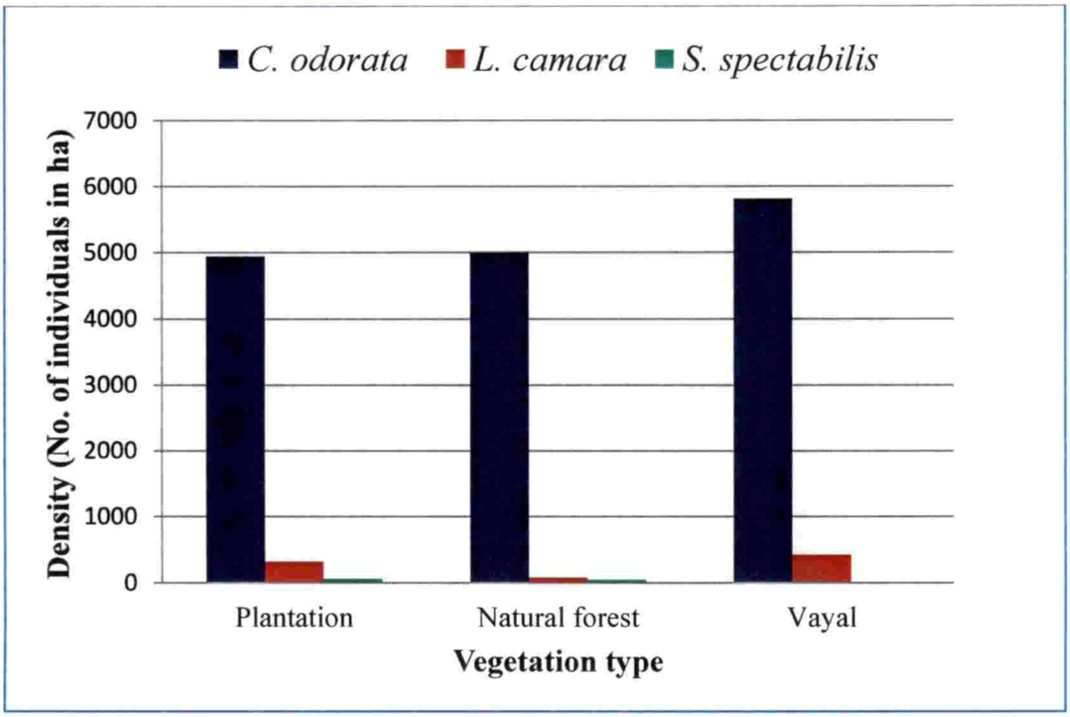


Figure 3. Density of IAPS in each vegetation type

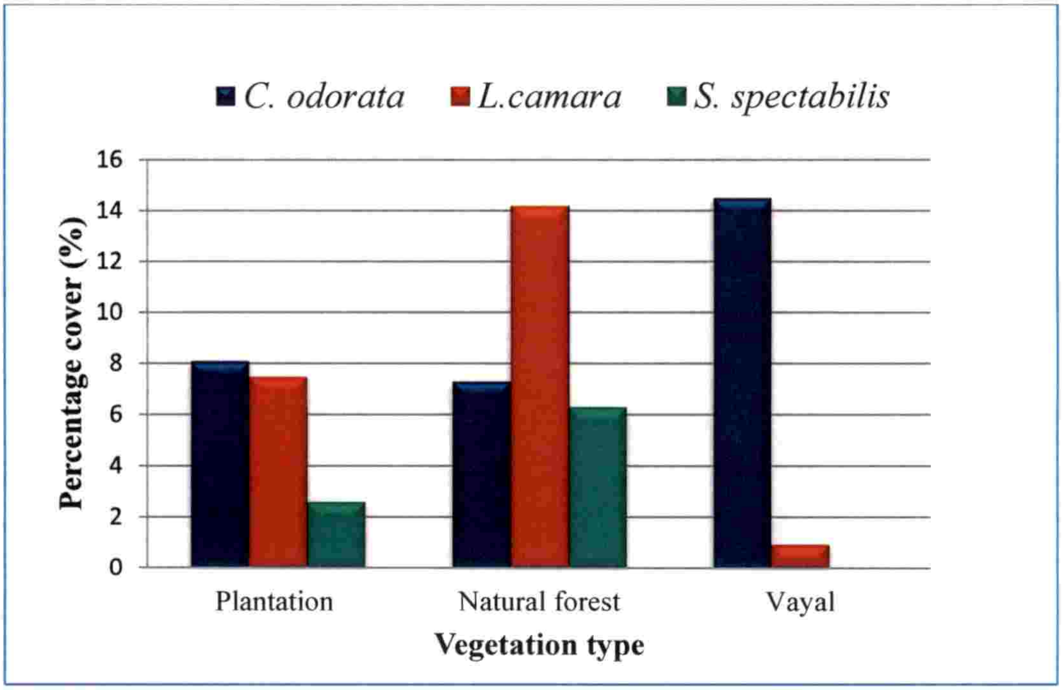


Figure 4. Percentage ground covered by selected IAPS in each vegetation type

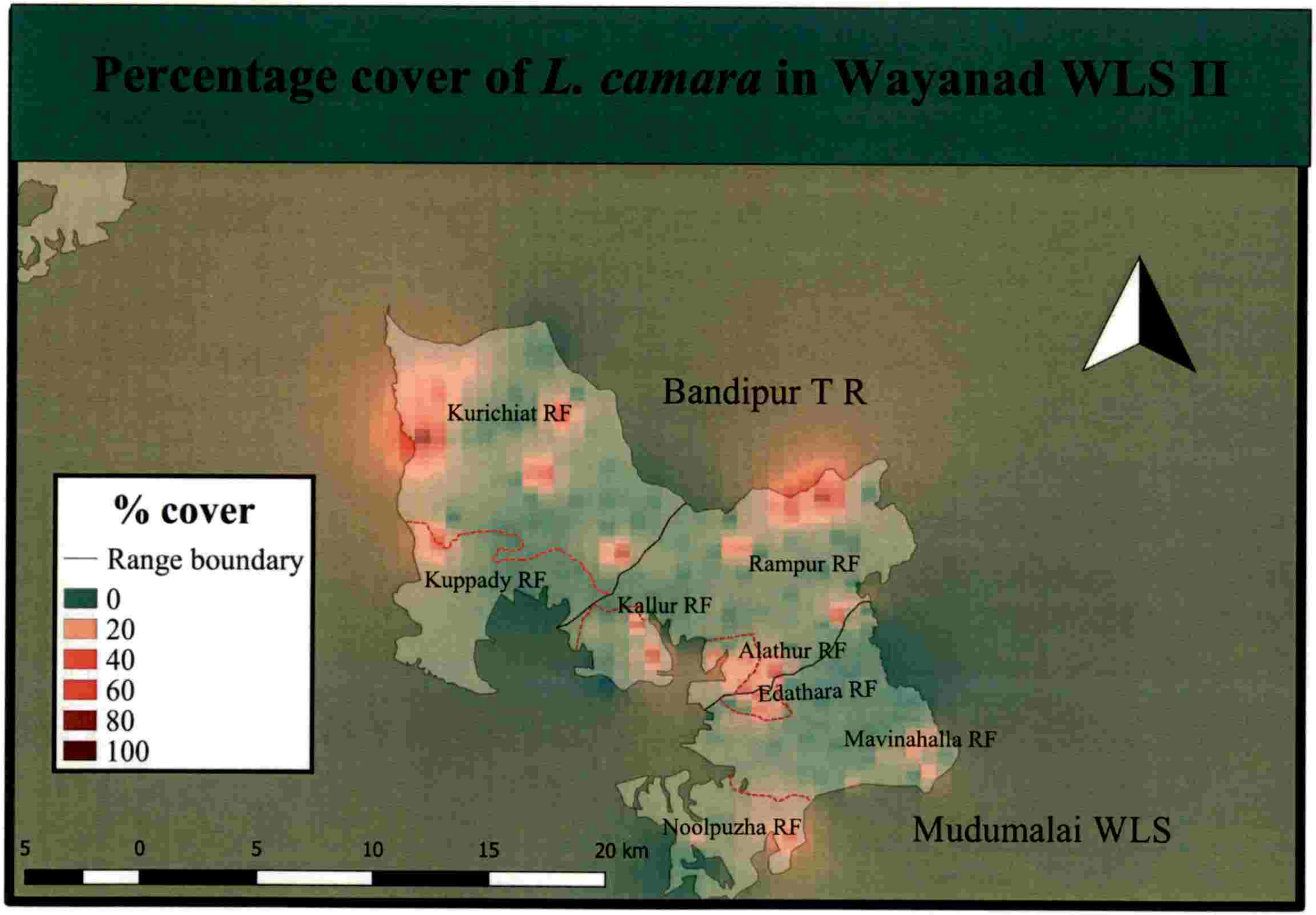


Figure 5. Distribution of *L. camara* in WS II part of Wayanad WLS

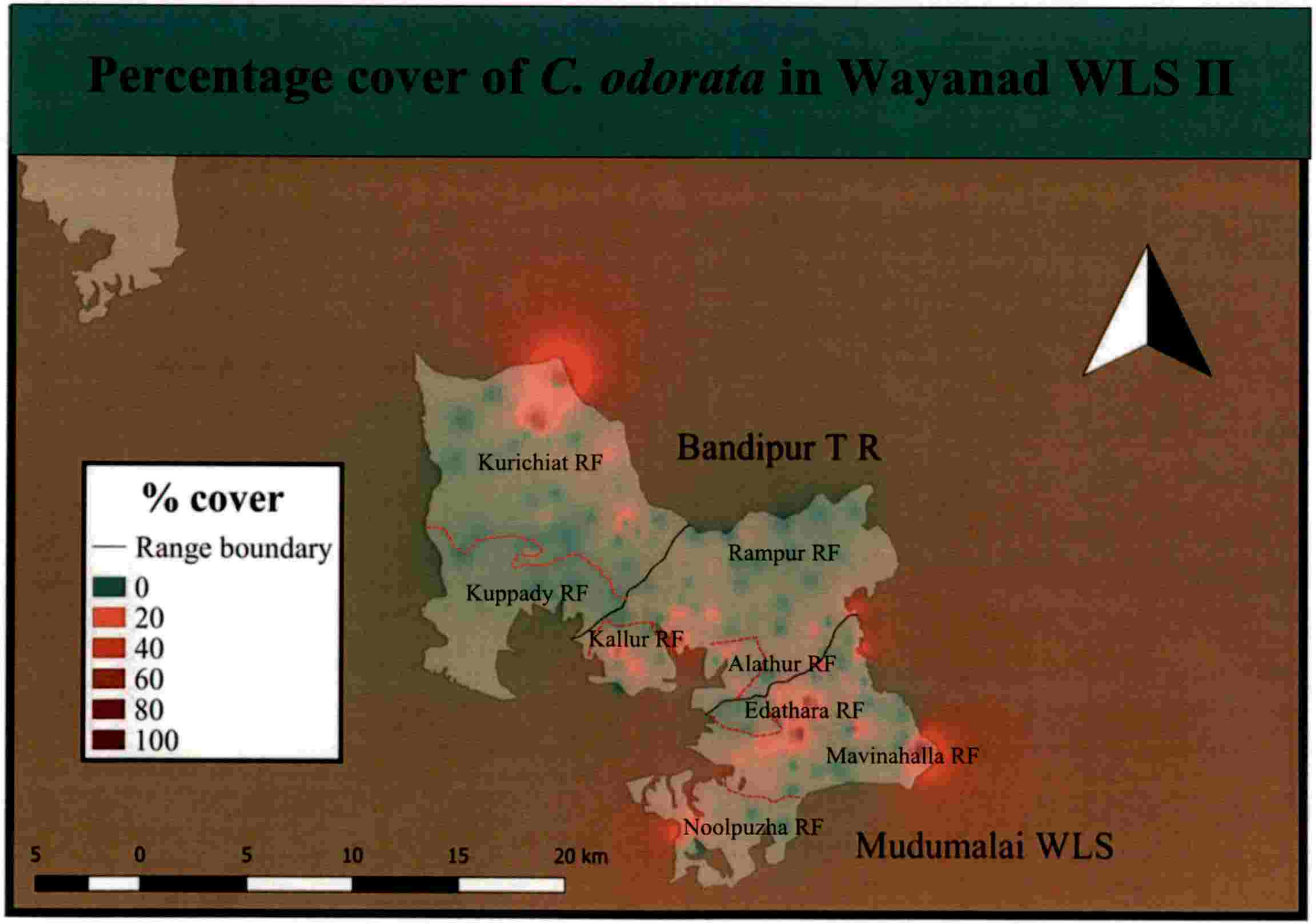


Figure 6. Distribution of *C. odorata* in WS II part of Wayanad WLS

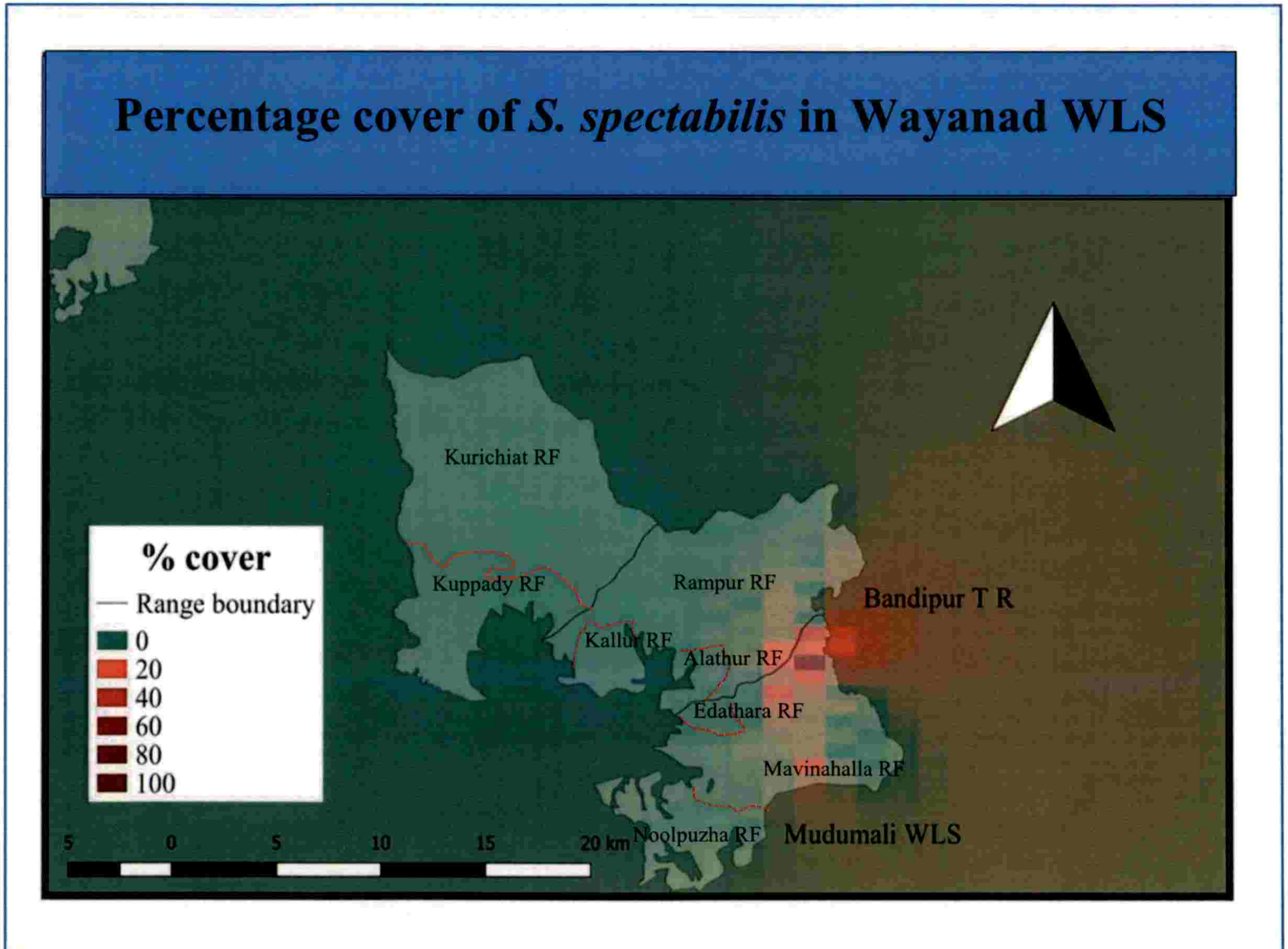


Figure 7. Distribution of *S. spectabilis* in WS II part of Wayanad WLS

4.2 DISTRIBUTION OF SELECTED IAPS

4.2.1 *L. camara*

It was distributed all over the sanctuary except in the borders of Sulthan bathery and Kurichiat range (Fig. 5). The high invasion of *L. camara* was seen in the Kurichiat RF (Kurichiat range), Rampur and Alathur RF in Sulthan bathery range and Edathara RF of Muthanga range. Less invasion of *Lantana* was seen in borders of Kurichiat and Sulthan bathery range. The borders of Mudumalai WLS and Mavinahalla RF were also free from *Lantana* invasion.

4.2.2 *C. odorata*

C. odorata was invaded all parts of WS II. High invasion of *Chromolaena* was found in Kurichiat RF of Kurichiat range, Mavinahalla and Noolpuzha RF of Muthanga range, Kallur and Rampur RF in Sulthan bathery range (Fig. 6). 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 and Mavinahalla RF.

4.2.3 *S. spectabilis*

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 occupied by *Senna*. The infestation of *Senna* has extended up to "Kakkapadam" in Muthanga range (2.5 km from Muthanga station). At present this region looked like *Senna* plantation. In a particular 10 m × 10 m sample plot, there will be 7 individuals of *Senna* at an average GBH of 70 cm. Each tree had a percentage cover of 35 m^2.

4.3 ASSESSMENT OF OTHER VEGETATION CHARACTERS

Natural forest showed comparatively high species richness than Plantation and Vayal. In natural forest there were 93 plant species. Plantation and vayal had 67 and 63 plant species respectively. Among the recorded plant species 55 were trees, 24 were shrubs, 35 herbs and 11 climbers (Table 6).

Among the tree species *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 brachiata, Dalbergia lanceolaria, Diospyros melanoxylon, Elaeocarpus variabilis, Gmelina arborea, Hydnocarpus pentandra, Miliusa tomentosa, Pongamia pinnata, Streblus asper* and *Terminalia paniculata* were only in NF. *Careya arborea* and *Trewia nudiflora* were seen only in vayal. In plantation, the species *Ailanthus triphysa, Elaeocarpus tuberculatus, Mallotus tetracoccus* and *Ziziphus mauritiana* were only present.

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

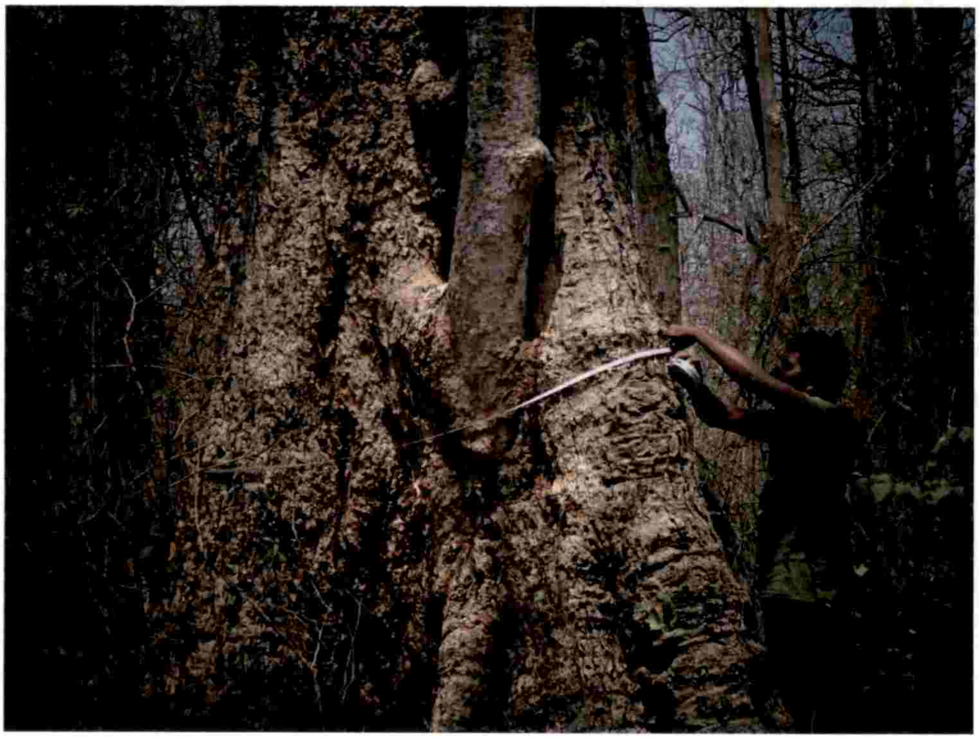


Plate 3. Assessment activities carried out in Wayanad Wildlife Sanctuary II

Catunaregam spinosa, Dendrocalamus strictus, Glycosmis pentaphylla, Sida acuta, Sida alnifolia and *Solanum aculeatissimum* are the shrubs which are seen in all the three vegetation types. *Canthium coromandelicum, Clerodendrum infortunatum, Flacourtia indica, Osbeckia aspera* and *Rauvolfia serpentina* were only seen in NF. *Calotropis gigantean* and *Flemingia strobilifera* were only seen in vayals.

Among the 11 climbers, *Hemidesmus indicus* and *Ziziphus oenoplia* were seen in all the vegetation types. *Caesalpinia mimosoides*, *Cosmostigma racemosum, Elaeagnus kologa* and *Piper nigrum* were seen only in NF. *Chonemorpha fragrans* was only seen in vayal. There were no specific climber species for plantation.

Table 6. List of plant species in the WS II of sanctuary

Sl no.	Species	Category	NF	Plantation	Vayal
1	*Ageratum conyzoides*	H	+	-	+
2	*Ailanthus triphysa*	T	-	+	-
3	*Annona squamosa*	T	+	-	+
4	*Anogeissus latifolia*	T	+	+	+
5	*Aporosa cardiosperma*	T	+	-	-
6	*Arundinella leptochloa*	H	-	-	+
7	*Axonopus compressus*	H	-	-	+
8	*Barleria mysorensis*	S	+	+	-
9	*Bauhinia malabarica*	T	-	-	+
10	*Bauhinia racemosa*	T	+	+	-
11	*Biophytum reinwardtii var reinwardtii*	H	+	+	+
12	*Butea monosperma*	T	+	+	+
13	*Caesalpinia mimosoides*	C	+	-	-
14	*Calotropis gigantea*	S	-	-	+
15	*Calycopteris floribunda*	C	+	+	-
16	*Canthium coromandelicum*	S	+	-	-
17	*Carallia brachiata*	T	+	-	-
18	*Cardiospermum halicacabum*	C	+	+	-
19	*Careya arborea*	T	-	-	+
20	*Carmona retusa*	S	+	+	-

21	*Caryota urens*	T	+	+	-
22	*Cassia fistula*	T	+	+	+
23	*Catunaregam spinosa*	S	+	+	+
24	*Centella asiatica*	H	+	-	-
25	*Chamaecrista absus*	H	+	-	-
26	*Chonemorpha fragrans*	C	-	-	+
27	*Cinnamomum veerum*	T	+	+	-
28	*Cipadessa baccifera*	S	+	+	-
29	*Clerodendrum infortunatum*	S	+	-	-
30	*Cosmostigma racemosum*	C	+	-	-
31	*Crassocephalum crepidioides*	H	+	+	+
32	*Curculigo orchioides*	H	+	+	+
33	*Curcuma neilgherrensis*	H	+	+	+
34	*Cyclea peltata*	C	+	+	-
35	*Cyperus pilosus*	H	-	-	+
36	*Dalbergia lanceolaria*	T	+	-	-
37	*Dalbergia latifolia*	T	-	+	+
38	*Dendrocalamus strictus*	S	+	+	+
39	*Desmodium gangeticum*	H	-	+	-
40	*Desmodium heterocarpon*	S	+	+	-
41	*Desmodium laxiflorum*	H	+	+	-
42	*Desmodium pulchellum*	S	+	+	-
43	*Desmodium trifolium*	H	-	-	+
44	*Digitaria ciliaris*	H	-	-	+
45	*Diospyros melanoxylon*	T	+	-	-
46	*Elaeagnus kologa*	C	+	-	-
47	*Elaeocarpus tuberculatus*	T	-	+	-
48	*Elaeocarpus variabilis*	T	+	-	-
49	*Elephantopus scaber*	H	+	+	+
50	*Eleutheranthera ruderalis*	H	+	+	+
51	*Eragrostis tenella*	H	-	-	+
52	*Eucalyptus globulus*	T	-	+	+
53	*Flacourtia indica*	S	+	-	-
54	*Flemingia strobilifera*	S	-	-	+
55	*Glycosmis pentaphylla*	S	+	+	+
56	*Gmelina arborea*	T	+	-	-
57	*Gomphrena celosioides*	H	-	+	-
58	*Grangea maderaspatana*	H	-	-	+

59	*Grewia tiliifolia*	T	+	+	-
60	*Haldina cordifolia*	T	+	-	+
61	*Helicteres isora*	S	+	+	-
62	*Hemidesmus indicus*	C	+	+	+
63	*Hydnocarpus pentandra*	T	+	-	-
64	*Hyptis suaveolens*	S	+	+	-
65	*Jansenella griffithiana*	H	-	-	+
66	*Kyllinga nemoralis*	H	-	-	+
67	*Lagerstroemia microcarpa*	T	+	+	+
68	*Lagerstroemia speciosa*	T	+	-	-
69	*Lannea coromandelica*	T	+	+	+
70	*Lepidagathis incurve*	H	+	+	+
71	*Leucaena leucocephala*	H	+	-	-
72	*Leucas asper*	H	+	-	+
73	*Lindernia crustacean*	H	+	-	-
74	*Ludwigia peruviana*	S	-	-	+
75	*Mallotus tetracoccus*	T	-	+	-
76	*Mangifera indica*	T	+	-	-
77	*Melastoma malabathricum*	S	+	-	+
78	*Melia azedarach*	T	+	+	-
79	*Melia dubia*	T	+	+	-
80	*Miliusa tomentosa*	T	+	-	-
81	*Mimosa pudica*	H	+	+	+
82	*Mimusops elengi*	T	+	+	-
83	*Mitracarpus hirtus*	H	+	+	+
84	*Naringi crenulata*	T	+	+	+
85	*Olea dioica*	T	+	+	+
86	*Osbeckia aspera*	S	+	-	-
87	*Panicum trypheron*	H	-	-	+
88	*Persea macrantha*	T	+	+	-
89	*Phyllanthus emblica*	T	+	-	+
90	*Piper nigrum*	C	+	-	-
91	*Pogostemon purpurascens*	H	-	+	-
92	*Pongamia pinnata*	T	+	-	-
93	*Premna mollissima*	T	+	-	-
94	*Pterocarpus marsupium*	T	+	+	+
95	*Rauvolfia serpentine*	S	+	-	-
96	*Rhynchospora corymbosa*	H	-	-	+

97	*Sacciolepis indica*	H	-	-	+
98	*Schleichera oleosa*	T	+	+	-
99	*Schrebera swietenioides*	T	+	-	-
100	*Semecarpus anacardium*	T	-	+	-
101	*Senna tora*	H	+	+	+
102	*Shorea roxburghii*	T	+	+	+
103	*Sida acuta*	S	+	+	+
104	*Sida alnifolia*	S	+	+	+
105	*Sida rhombifolia*	S	-	+	-
106	*Solanum aculeatissimum*	S	+	+	+
107	*Spathodea campanulata*	T	+	-	-
108	*Sporobolus tenuissimus*	H	-	-	+
109	*Stachyphrynium jamaicensis*	S	+	+	-
110	*Streblus asper*	T	+	-	-
111	*Syzygium cumini var. cumini*	T	+	+	+
112	*Tabernamontana alternifolia*	T	+	+	+
113	*Tamilnadia uliginosa*	T	+	-	+
114	*Tectona grandis*	T	+	+	+
115	*Terminalia bellirica*	T	+	+	+
116	*Terminalia cuneata*	T	+	-	+
117	*Terminalia elliptica*	T	+	+	+
118	*Terminalia paniculata*	T	+	-	-
119	*Themeda triandra*	H	-	-	+
120	*Trewia nudiflora*	T	-	-	+
121	*Triumfetta rhomboidea*	S	+	+	-
122	*Vitex altissima*	T	+	-	-
123	*Ziziphus glabrata*	T	+	-	-
124	*Ziziphus mauritiana*	T	-	+	-
125	*Ziziphus oenoplia*	C	+	+	+
	Total		93	67	63

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

Alstonia scholaris

Bauhinia racmeosa

Caesalpinia mimosoides

Careya arboea

Curculigo orchioides

Cyclea peltata

Plate 4. Common species found in Wayanad Wildlife Sanctuary II

Dalbergia latifolia

Desmodium triflorum

Elephantopus scaber

Grewia tilifolia

Glycosmis pentaphylla

Pterocarpus marsupium

Plate 5. Common species found in Wayanad Wildlife Sanctuary II

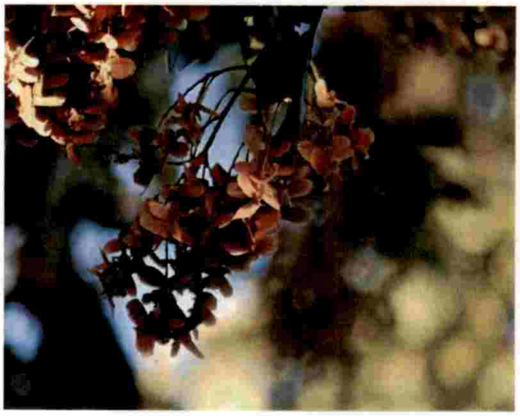
Melastoma malabathricum

Senna tora

Sida acuta

Sida alnifolia

Shorea roxburghii



Terminalia paniculata

Plate 6. Common species found in Wayanad Wildlife Sanctuary II

Terminalia eliptica

Tabernaemontana alternifolia

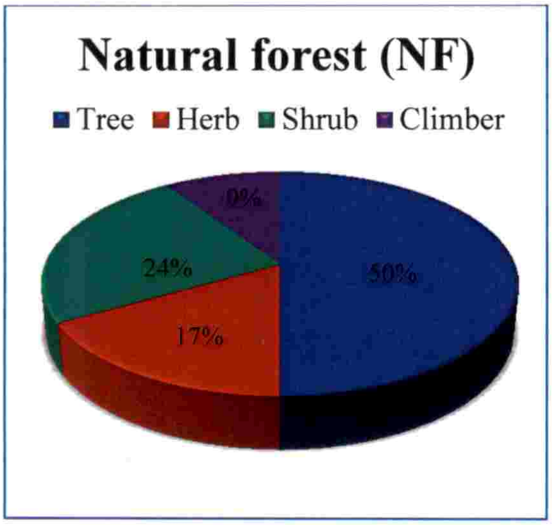
Biophytum reinwardtii

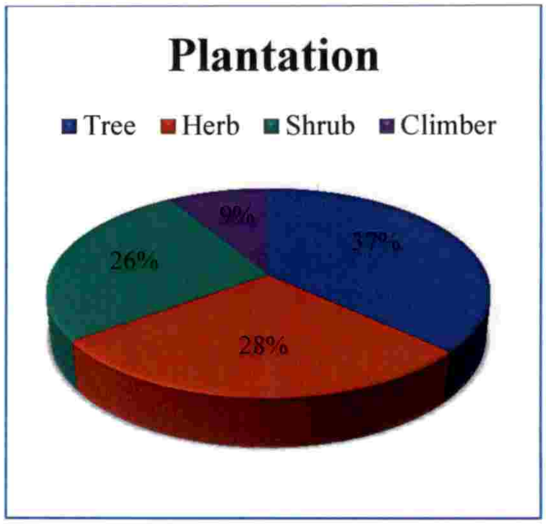
Calycopteris floribunda

Cinnamomum verum

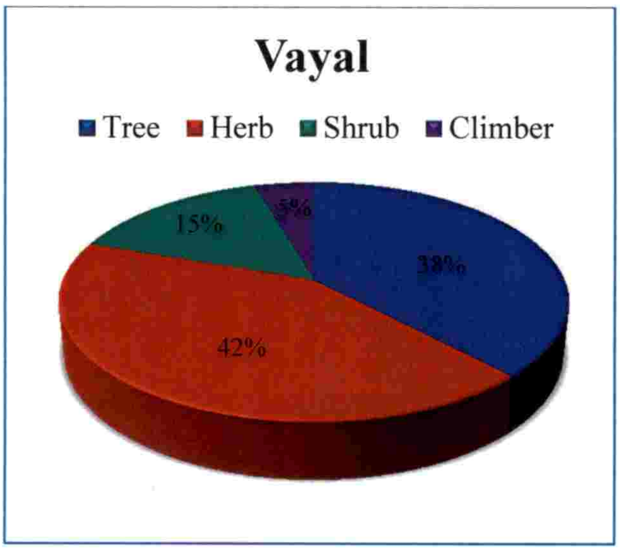
Ziziphus oenoplia

Plate 7. Common species found in Wayanad Wildlife Sanctuary





(a) (b)



(c)

Figure 8. Percentage distribution of vegetation in Natural forest (a), Plantation (b) and Vayal (c)

About 125 plant species were identified from WS II of Wayanad WLS (Table 6). The Control plots have a maximum of 99 plant species which accounted about 79.2% of the total species found in the study area (Table 7). *Lantana camara* infested areas had 50 species and *C. odorata* infested areas has 86 species. *Senna spectabilis* invaded sites had only 13 plant species. Most of the areas were invaded by both *Lantana* and *Chromolaena*. About 66 plants were identified from LC areas. Only 4 species other than *Chromolaena* and *Senna* were identified from the CS plots. Those areas which were invaded by all the three IAPS had 13 plant species. *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* were only seen in control plots. The species *B. racemosa, C. racemosum* and *E. variabilis* were only seen in *Lantana* infected plots. Certain species like *C. gigantea, L. leucocephala, M. malabathricum* and *S. jamaicensis* were only seen in *Chromolaena* infected plots.

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

Sl. No.	Species	L	C	S	LC	CS	LCS	Control
1	*Ageratum conyzoides*	+	+	–	+	–	–	–
2	*Ailanthus triphysa*	–	+	–	–	–	–	+
3	*Annona squamosa*	–	+	–	–	–	–	+
4	*Anogeissus latifolia*	+	–	+	+	–	+	+
5	*Aporosa cardiosperma*	–	–	–	–	–	–	+
6	*Arundinella leptochloa*	+	+	–	+	–	–	+
7	*Axonopus compressus*	–	+	–	–	–	–	+
8	*Barleria mysorensis*	+	+	–	–	–	–	–
9	*Bauhinia malabarica*	–	+	–	–	–	–	+
10	*Bauhinia racemosa*	+	–	–	–	–	–	–
11	*Biophytum reinwardtii var reinwardtii*	+	+	–	+	–	–	+
12	*Butea monosperma*	+	+	–	+	–	+	+
13	*Caesalpinia mimosoides*	+	–	–	+	–	–	–
14	*Calotropis gigantea*	–	+	–	–	–	–	–
15	*Calycopteris floribunda*	–	+	–	+	–	–	+
16	*Canthium coromandelicum*	–	–	–	–	–	–	+
17	*Carallia brachiata*	–	–	–	+	–	–	+
18	*Cardiospermum halicacabum*	–	–	–	+	–	–	+
19	*Careya arborea*	+	–	–	–	–	–	+
20	*Carmona retusa*	–	+	+	+	–	–	+
21	*Caryota urens*	–	+	–	–	–	–	+
22	*Cassia fistula*	+	+	+	+	–	–	+
23	*Catunaregam spinosa*	–	+	–	–	–	–	+
24	*Centella asiatica*	–	–	+	–	–	–	+
25	*Chamaecrista absus*	–	+	–	–	–	–	–
26	*Chonemorpha fragrans*	+	+	–	+	–	–	–
27	*Cinnamomum veerum*	–	+	–	–	–	–	+
28	*Cipadessa baccifera*	+	+	–	+	–	+	+
29	*Clerodendrum infortunatum*	–	–	–	–	–	–	+
30	*Cosmostigma racemosum*	+	–	–	–	–	–	–
31	*Crassocephalum crepidioides*	+	+	+	+	–	+	+
32	*Curculigo orchioides*	+	+	–	+	–		+
33	*Curcuma neilgherrensis*	+	+	–	+	–	+	+
34	*Cyclea peltata*	–	+	–		–	–	+

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35	*Cyperus pilosus*	–	–	–	+	–	–	+
36	*Dalbergia lanceolaria*	+	+	–	+	–	–	–
37	*Dalbergia latifolia*	+	+	–	+	–	+	+
38	*Dendrocalamus strictus*	–	+	–	–	+	+	+
39	*Desmodium heterocarpon*	–	+	–	+	–	–	–
40	*Desmodium laxiflorum*	–	+	–	+	–	–	+
41	*Desmodium pulchellum*	+	+	–	+	–	–	–
42	*Desmodium trifolium*	–	+	–	–	–	–	+
43	*Digitaria ciliaris*	+	+	–	+	–	–	+
44	*Diospyros melanoxylon*	+	–	–	+	–	–	+
45	*Elaeagnus kologa*	–	–	–	–	–	–	+
46	*Elaeocarpus tuberculatus*	–	–	–	–	–	–	+
47	*Elaeocarpus variabilis*	+	–	–	–	–	–	–
48	*Elephantopus scaber*	+	+	–	+	–	–	+
49	*Eleutheranthera ruderalis*	+	+	–	+	–	–	+
50	*Eleutheranthera ruderalis*	–	+	–	+	–	–	–
51	*Eragrostis tenella*	+	+	–	+	–	–	+
52	*Eucalyptus globulus*	–	+	+	–	–	–	–
53	*Flacourtia indica*	–	–	–	–	–	–	+
54	*Flemingia strobilifera*	–	–	–	–	–	–	+
55	*Glycosmis pentaphylla*	+	+	+	+	–	+	+
56	*Gmelina arborea*	–	+	–	+	–	+	+
57	*Gomphrena celosioides*	–	+	–	–	–	–	+
58	*Grangea maderaspatana*	–	+	–	–	–	–	+
59	*Grewia tiliifolia*	–	+	–	+	–	–	+
60	*Haldina cordifolia*	–	+	+	+	+	+	+
61	*Helicteres isora*	+	+	+	+	–	+	+
62	*Hemidesmus indicus*	–	+	–	–	–	–	+
63	*Hydnocarpus pentandra*	–	–	–	–	–	–	+
64	*Hyptis suaveolens*	+	–	–	+	–	–	–
65	*Jansenella griffithiana*	+	+	–	+	–	–	+
66	*Kyllinga nemoralis*	–	+	–	–	–	–	+
67	*Lagerstroemia microcarpa*	+	+	–	+	–	–	+
68	*Lagerstroemia speciosa*	+	–	–	+	–	–	–
69	*Lannea coromandelica*	–	–	–	+	–	–	+
70	*Lepidagathis incurva*	–	+	+	–	–	–	+
71	*Leucaena leucocephala*	–	+	–	–	–	–	–
72	*Leucas asper*	–	+	–	–	–	–	+

73	*Lindernia crustacea*	–	–	–	–	–	–	+
74	*Ludwigia peruviana*	–	–	–	–	–	–	+
75	*Mallotus tetracoccus*	–	–	–	–	–	–	+
76	*Mangifera indica*	–	–	–	+	–	–	+
77	*Melastoma malabathricum*	–	+	–	–	–	–	–
78	*Melia azedarach*	–	–	–	–	–	–	+
79	*Melia dubia*	+	+	–	–	–	–	+
80	*Miliusa tomentosa*	–	–	–	–	–	–	+
81	*Mimosa diplotricha*	+	+	+	+	+	–	+
82	*Mimusops elengi*	+	+	–	+	–	–	+
83	*Mitracarpus hirtus*	–	+	–	+	–	–	–
84	*Naringi crenulata*	–	+	–	+	–	–	+
85	*Olea dioica*	+	+	–	+	–	–	+
86	*Osbeckia aspera*	–	–	–	–	–	–	+
87	*Panicum trypheron*	–	+	–	+	–	–	+
88	*Persea macrantha*	+	+	–	+	–	–	+
89	*Phyllanthus emblica*	+	+	–	–	–	–	+
90	*Piper nigrum*	–	–	–	–	–	–	+
91	*Pogostemon purpurascens*	–	+	–	+	–	–	–
92	*Pongamia pinnata*	–	+	–	+	–	–	+
93	*Premna mollissima*	–	–	–	–	–	–	–
94	*Pterocarpus marsupium*	+	+	–	–	–	–	+
95	*Rauvolfia serpentina*	–	–	–	–	–	–	+
96	*Rhynchospora corymbosa*	–	+	–	–	–	–	+
97	*Sacciolepis indica*	+	+	–	+	–	–	–
98	*Schleichera oleosa*	+	+	–	+	–	–	+
99	*Schrebera swietenioides*	–	–	–	+	–	–	+
100	*Semecarpus anacardium*	–	+	–	–	–	–	+
101	*Senna spectabilis*	–	–	–	–	–	–	–
102	*Senna tora*	+	+	–	+	–	–	–
103	*Shorea roxburghii*	+	+	–	+	–	–	+
104	*Sida acuta*	–	+	–	+	–	–	–
105	*Sida alnifolia*	–	+	–	+	–	–	+
106	*Sida rhombifolia*	–	+	–	–	–	–	+
107	*Solanum aculeatissimum*	+	+	–	+	–	+	+
108	*Spathodea campanulata*	+	+	–	+	–	–	+
109	*Sporobolus tenuissimus*	+	+	–	+	–	–	+
110	*Stachyphrynium jamaicensis*	–	+	–	–	–	–	–

111	*Streblus asper*	–	–	–	–	–	–	+
112	*Syzygium cumini var. cumini*	+	+	–	+	–	–	+
113	*Tabernamontana alternifolia*	+	+	–	+	–	–	+
114	*Tamilnadia uliginosa*	–	+	–		–	–	–
115	*Tectona grandis*	+	+	+	+	–	–	+
116	*Terminalia bellirica*	–	+	–	–	–	–	+
117	*Terminalia cuneata*	–	–	–	+	–	–	+
118	*Terminalia elliptica*	+	+	+	+	+	+	+
119	*Terminalia paniculata*	+	–	–	–	–	–	+
120	*Trewia nudiflora*	–	+	–	–	–	–	+
121	*Triumfetta rhomboidea*	–	+	–	–	–	–	+
122	*Vitex altissima*	–	–	–	–	–	–	+
123	*Ziziphus glabrata*	–	+	–	+	–	–	+
124	*Ziziphus mauritiana*	–	–	–	–	–	–	+
125	*Ziziphus oenoplia*	–	+	–	+	–	–	+
	Total	50	86	13	66	4	13	99

(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

The mean species richness (MSR) in each vegetation type was calculated (Table 8). Natural forest has the highest species richness value and the lowest value was in vayal (Fig. 10). Among the seven vegetation types it was the control plot which had the maximum species richness (Fig. 9). The lowest species richness was found in S (*S. spectabilis*), CS (*C. odorata* and *S. spectabilis*) and LCS (*L. camara, C .odorata* and *S. spectabilis*) plots. The control plot in NF has mean species richness (MSR) of 29.7 and it was the highest MSR in the sanctuary (Fig. 9). The LC and C plots in NF have 16.5 and 22.4 MSR respectively. The MSR of S and LCS plots are 5.2 and 28.7 respectively. The CS plots (3) have the least MSR. In plantation, the maximum MSR was in control plots (22.2). The MSR of LC plots in plantation was 18.7, bears the second highest MSR in plantation. The C and LCS plots have MSR 12.7 and 10 respectively. The least MSR in plantation was seen in S and CS plots (3). In vayal, the MSR in control plot was 22.3. Second highest MSR in vayal was obtained from C plots (17.1). The least MSR in vayal was from L (11.6) plots. Since there is no *Senna* infestation in vayal, there were no S, CS and LCS plots. By combining the MSR of Seven weed categories in three vegetation types, it was found that the control plots had the highest MSR (Fig. 11). It was followed by L and LC plots. The lowest MSR was found in S, CS and LCS plots.

The species richness of native species among habitat ($F_{2, 235} = 7.04$; $p<0.001$) and weed category areas ($F_{6, 235} = 43.61$ $p<0.001$) have significant variations. The interaction between vegetation type and weed category areas also showed significant variation ($F_{12, 235} = 3.16$ $p<0.001$).

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	LCS	Control
Natural forest	22.4±6.5	10.6 ± 6.2	5.2± 2.3	16.5 ± 4.5	3.0	28.7±3.4	29.7 ± 3.4
Plantation	15 ± 3.4	12.7 ± 4.1	3 ± 1.4	18.7 ± 8	3.0	10 ± 4.3	22.2 ± 5.9
Vayal	11.6±3.6	10.1 ± 6.4	0.0	12.7 ± 3.6	0.0	0.0	22.3 ± 2.8

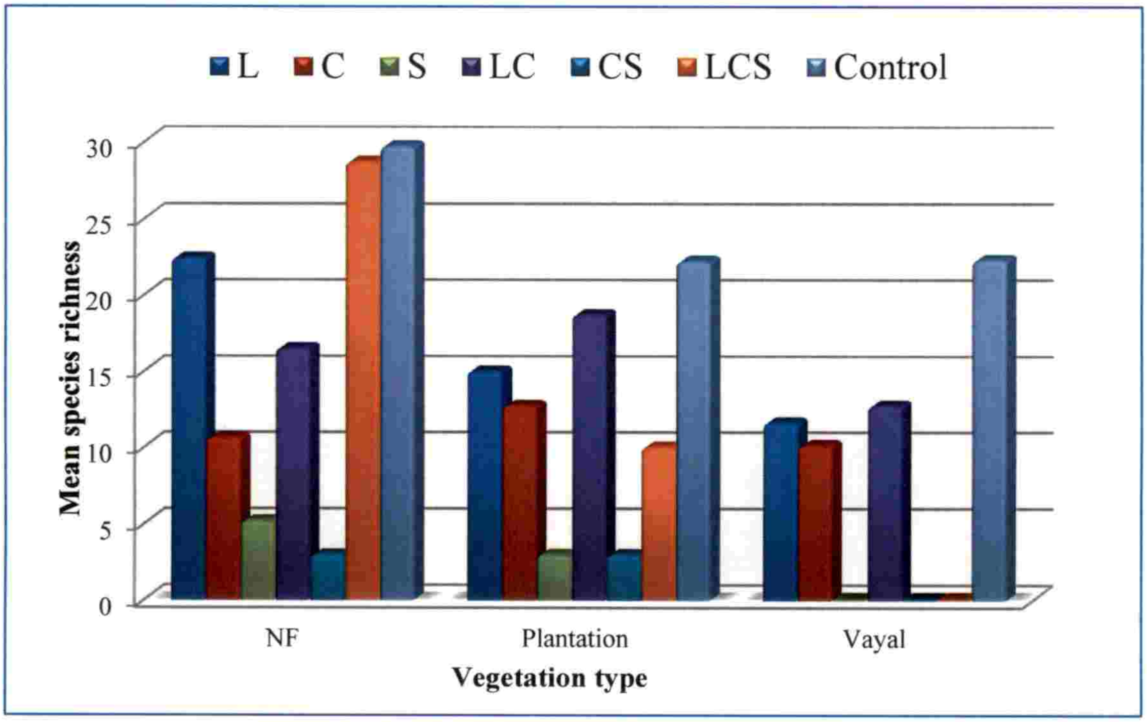

Figure 9. Mean species richness among weed category areas in three vegetation types

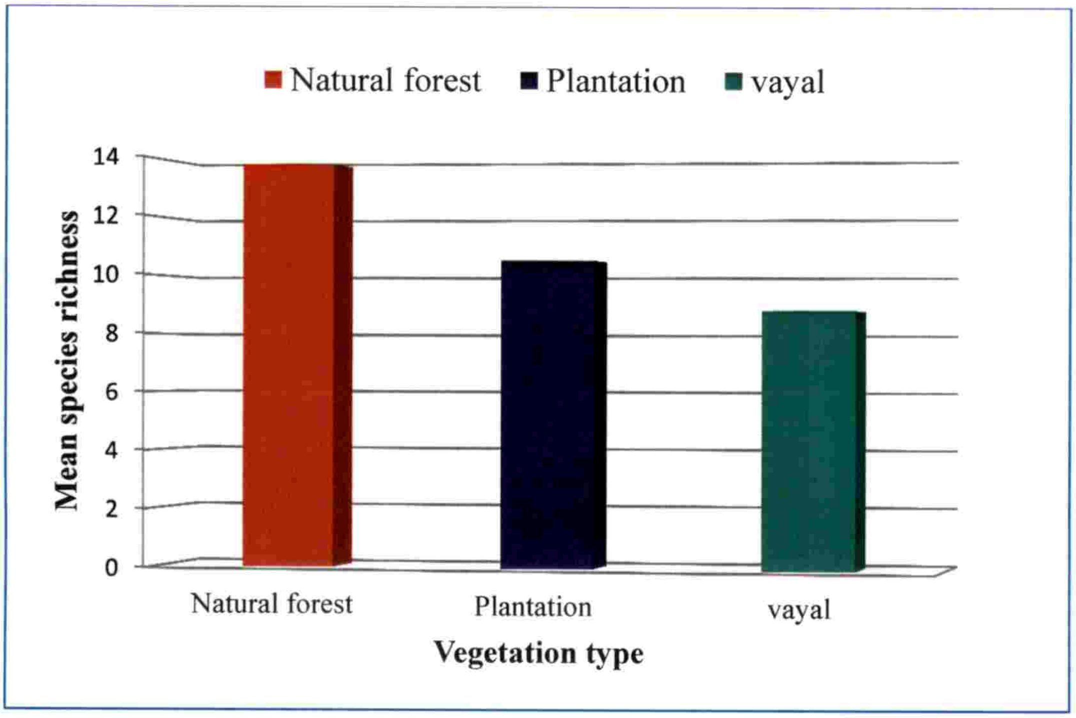

Figure 10. Means of species richness in three vegetation types

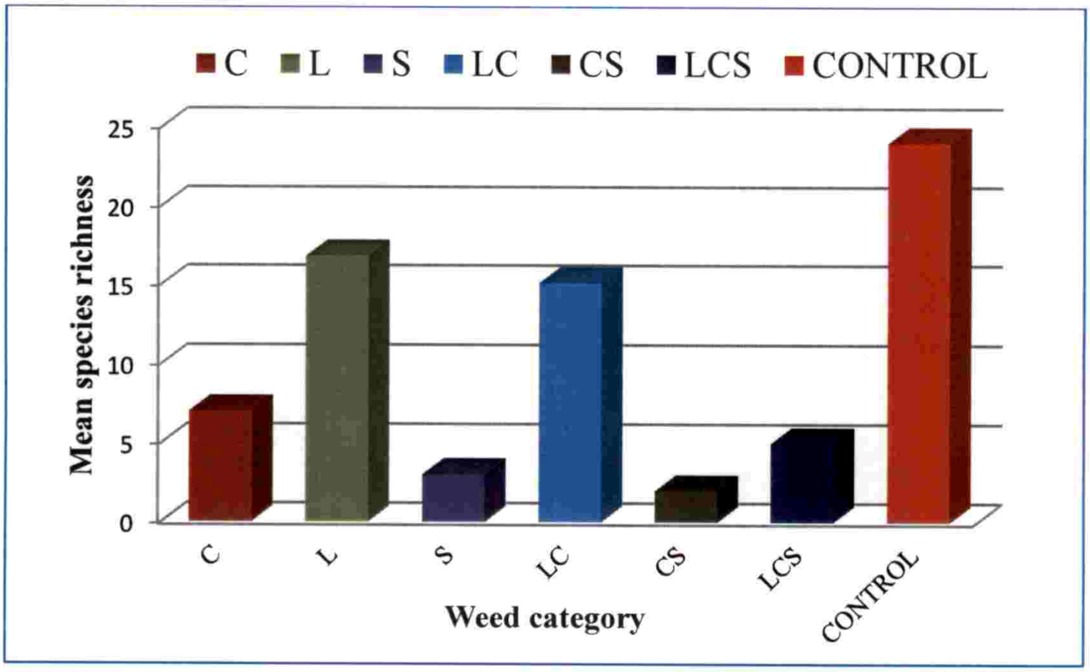

Figure 11. Means of species richness in weed category areas

4.4.2 Phytosociological analysis

The Phytosociological analysis in plantation found that maximum frequency was showed by *C. odorata* (75.29), followed by *G. pentaphylla* (44.7), *L. camara* (44.5) and *M. pudica* (44.9) (Table 9). After *C. odorata* (65.6), *S. jamaicensis* (38.5) showed the second highest abundance. The highest frequency in plantation was shown by *T. grandis* (87.05), which means that 87.05 % of the total sample plots have *T. grandis*. It was followed by *C. odorata* (75.29) and *M. pudica* (49.4). The frequency of *L. camara* was 45.8%. *Glycosmis pentaphylla* is the native species that showed maximum frequency, but it is only half of *Chromolaena*'s frequency. The least frequency was shown by *B. mysorensis, B. racemosa, L. coromandelica, M. azedarach* and *M. elengi.*

The vegetation analysis in NF showed that *C. odorata* has maximum abundance (81.6) and frequency (61.1) (Table 10). After *C. odorata*, *S. jamaicensis* (31.3) has maximum abundance. The abundance of *S. spectabilis* and *L. camara* were 17.7 and 9.8 respectively. *C. odorata* and *L. camara* were the densely seen plant species in the natural forest. There were about 4996 individuals of *C. odorata* in 1 ha. The density of *L. camara* was 532.9 stems ha^{-1}. After *L. camara*, *G. pentaphylla* (338.8 stems ha^{-1}) and *M. hirtus* (195.2 stems ha^{-1}) were the densely seen plant species in NF. The most densely seen tree species in NF is *S. spectabilis* (188.2 stems ha^{-1}). Among the first ten highly dense plant species in NF, five were IAPS. Maximum frequency in NF was shown by *C. odorata* (61.1) and *L. camara* (54.1). Compared to *Lantana* and *Chromolaena*, *S. spectabilis* shows less frequency (10.58). *T. elliptica* (50.5) was the tree species having the highest frequency, followed by *L. microcarpa* (31.7) and *O. dioica* (35.8). It is *A. squamosa* which has the lowest frequency, abundance and density in NF.

The most densely seen plant species in vayal was *A. leptochloa* (11662 stems ha^{-1}) (Table 11). Density of *C. odorata* (5810.6 stems ha^{-1}) was only half of *A. leptochloa*. After *C. odorata*, highest density was shown by *K. nemoralis* (4289.4 stems ha^{-1}) and *A. compressus* (2917.6 stems ha^{-1}). The lowest density in vayal was shown by *B. malabarica, C. fragrans* and *L. coromandelica.* The most abundantly seen plant species in vayal was *K. nemoralis* (173.6). It was followed by *A. leptochloa* (165.3) and *A. compressus* (139.6). The abundance of *C. odorata* and *L. camara* were 65 and 9.73 respectively. In vayal *A. conyzoides* (72.56) was more abundantly seen than *C. odorata.* The highest frequency in vayal was shown by *C. odorata* (89.4) and *A. leptochloa* (83.5). The lowest frequency was shown *by B. malabarica, C. fragrans, L. coromandelica, T. nudiflora, L. incurve, L. peruviana* and *A. squamosa.* The frequency of *L. camara* was 43.53.

Table 9. Phytosociological analysis of vegetation in plantation

Sl no	**Species**	**F**	**RF (%)**	**D (Individuals/ha)**	**RD (%)**	**Abundance**
1	*Acalypha paniculata*	1.18	0.13	2.35	0.03	2.00
2	*Ailanthus triphysa*	5.88	0.64	7.06	0.09	1.20
3	*Anogeissus latifolia*	14.12	1.54	14.12	0.17	1.00
4	*Barleria mysorensis*	1.18	0.13	1.18	0.01	1.00
5	*Bauhinia racemosa*	1.18	0.13	1.18	0.01	1.00
6	*Biophytum reinwardtii var reinwardtii*	2.35	0.26	5.88	0.07	2.50
7	*Butea monosperma*	2.35	0.26	2.35	0.03	1.00
8	*Calycopteris floribunda*	2.35	0.26	4.71	0.06	2.00
9	*Cardiospermum halicacabum*	3.53	0.38	3.53	0.04	1.00
10	*Carmona retusa*	3.53	0.38	3.53	0.04	1.00
11	*Caryota urens*	2.35	0.26	2.35	0.03	1.00
12	*Cassia fistula*	42.35	4.62	83.53	1.01	1.97
13	*Catunaregam spinosa*	21.18	2.31	31.76	0.38	1.50
14	*Chromolaena odorata*	75.29	8.21	4943.53	59.56	65.66
15	*Cinnamomum veerum*	4.71	0.51	11.76	0.14	2.50

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

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16	*Cipadessa baccifera*	11.76	1.28	14.12	0.17	1.20
17	*Crassocephalum crepidioides*	24.71	2.69	35.29	0.43	1.43
18	*Curculigo orchioides*	10.59	1.15	84.71	1.02	8.00
19	*Curcuma neilgherrensis*	15.29	1.67	72.94	0.88	4.77
20	*Cyclea peltata*	10.59	1.15	17.65	0.21	1.67
21	*Dalbergia latifolia*	27.06	2.95	34.12	0.41	1.26
22	*Dendrocalamus strictus*	14.12	1.54	37.65	0.45	2.67
23	*Desmodium gangeticum*	1.18	0.13	2.35	0.03	2.00
24	*Desmodium heterocarpon*	2.35	0.26	2.35	0.03	1.00
25	*Desmodium laxiflorum*	7.06	0.77	7.06	0.09	1.00
26	*Desmodium pulchellum*	9.41	1.03	14.12	0.17	1.50
27	*Elaeocarpus tuberculatus*	2.35	0.26	16.47	0.20	7.00
28	*Elephantopus scaber*	23.53	2.56	101.18	1.22	4.30
29	*Eleutheranthera ruderalis*	1.18	0.13	4.71	0.06	4.00
30	*Eucalyptus globulus*	12.94	1.41	75.29	0.91	5.82
31	*Glycosmis pentaphylla*	44.71	4.87	484.71	5.84	10.84
32	*Gomphrena celosioides*	3.53	0.38	9.41	0.11	2.67
33	*Grewia tiliifolia*	10.59	1.15	16.47	0.20	1.56
34	*Helicteres isora*	29.41	3.21	67.06	0.81	2.28
35	*Hemidesmus indicus*	8.24	0.90	68.24	0.82	8.29
36	*Hyptis suaveolens*	1.18	0.13	4.71	0.06	4.00
37	*Lagerstroemia microcarpa*	17.65	1.92	20.00	0.24	1.13
38	*Lannea coromandelica*	1.18	0.13	1.18	0.01	1.00
39	*Lantana camara*	45.88	5.00	322.35	3.88	7.03
40	*Lepidagathis incurva*	4.71	0.51	28.24	0.34	6.00
41	*Mallotus tetracoccus*	4.71	0.51	9.41	0.11	2.00
42	*Melia azedarach*	1.18	0.13	1.18	0.01	1.00
43	*Melia dubia*	11.76	1.28	57.65	0.69	4.90
44	*Mikania micrantha*	2.35	0.26	11.76	0.14	5.00
45	*Mimosa pudica*	49.41	5.38	183.53	2.21	3.71
46	*Mimusops elengi*	1.18	0.13	1.18	0.01	1.00
47	*Mitracarpus hirtus*	11.76	1.28	147.06	1.77	12.50
48	*Naringi crenulata*	2.35	0.26	2.35	0.03	1.00
49	*Olea dioica*	16.47	1.79	42.35	0.51	2.57
50	*Persea macrantha*	1.18	0.13	4.71	0.06	4.00
51	*Pogostemon purpurascens*	3.53	0.38	50.59	0.61	14.33
52	*Pterocarpus marsupium*	2.35	0.26	2.35	0.03	1.00

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53	*Schleichera oleosa*	18.82	2.05	92.94	1.12	4.94
54	*Semecarpus anacardium*	18.82	2.05	25.88	0.31	1.38
55	*Senna spectabilis*	8.24	0.90	63.53	0.77	7.71
56	*Senna tora*	3.53	0.38	38.82	0.47	11.00
57	*Shorea roxburghii*	12.94	1.41	17.65	0.21	1.36
58	*Sida acuta*	12.94	1.41	14.12	0.17	1.09
59	*Sida alnifolia*	25.88	2.82	54.12	0.65	2.09
60	*Sida rhombifolia*	8.24	0.90	8.24	0.10	1.00
61	*Solanum aculeatissimum*	11.76	1.28	21.18	0.26	1.80
62	*Stachyphrynium jamaicensis*	2.35	0.26	90.59	1.09	38.50
63	*Syzygium cumini var. cumini*	8.24	0.90	20.00	0.24	2.43
64	*Tabernamontana alternifolia*	23.53	2.56	41.18	0.50	1.75
65	*Tectona grandis*	87.06	9.49	564.71	6.80	6.49
66	*Terminalia bellirica*	2.35	0.26	2.35	0.03	1.00
67	*Terminalia elliptica*	4.71	0.51	14.12	0.17	3.00
68	*Triumfetta rhomboidea*	15.29	1.67	23.53	0.28	1.54
69	*Ziziphus mauritiana*	5.88	0.64	5.88	0.07	1.00
70	*Ziziphus oenoplia*	14.12	1.54	25.88	0.31	1.83
	Total	**917.65**	**100**	**8300**	**100**	**321.66**

Table 10. Phytosociological analysis of vegetation in Natural forest

Sl no.	**Species**	**F**	**RF (%)**	**D (Individuals/ha)**	**RD**	**A**
1	*Ageratum conyzoides*	11.76	1.14	61.18	0.60	5.20
2	*Annona squamosa*	1.18	0.11	1.18	0.01	1.00
3	*Anogeissus latifolia*	9.41	0.91	12.94	0.13	1.38
4	*Aporosa cardiosperma*	5.88	0.57	8.24	0.08	1.40
5	*Barleria mysorensis*	1.18	0.11	1.18	0.01	1.00
6	*Bauhinia racemosa*	1.18	0.11	1.18	0.01	1.00
7	*Biophytum reinwardtii var reinwardtii*	2.35	0.23	10.59	0.10	4.50
8	*Butea monosperma*	9.41	0.91	10.59	0.10	1.13
9	*Caesalpinia mimosoides*	1.18	0.11	17.65	0.17	15.00
10	*Calycopteris floribunda*	18.82	1.83	37.65	0.37	2.00
11	*Canthium coromandelicum*	1.18	0.11	2.35	0.02	2.00

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

12	*Carallia brachiata*	15.29	1.48	37.65	0.37	2.46
13	*Cardiospermum halicacabum*	8.24	0.80	10.59	0.10	1.29
14	*Carmona retusa*	15.29	1.48	18.82	0.18	1.23
15	*Caryota urens*	3.53	0.34	7.06	0.07	2.00
16	*Cassia fistula*	28.24	2.74	57.65	0.56	2.04
17	*Catunaregam spinosa*	10.59	1.03	11.76	0.11	1.11
18	*Centella asiatica*	1.18	0.11	2.35	0.02	2.00
19	*Chamaecrista absus*	1.18	0.11	2.35	0.02	2.00
20	*Chromolaena odorata*	61.18	5.94	4996.47	48.69	81.67
21	*Cinnamomum veerum*	11.76	1.14	52.94	0.52	4.50
22	*Cipadessa baccifera*	4.71	0.46	8.24	0.08	1.75
23	*Clerodendrum infortunatum*	1.18	0.11	2.35	0.02	2.00
24	*Cosmostigma racemosum*	1.18	0.11	2.35	0.02	2.00
25	*Crassocephalum crepidioides*	8.24	0.80	11.76	0.11	1.43
26	*Curculigo orchioides*	3.53	0.34	44.71	0.44	12.67
27	*Curcuma neilgherrensis*	17.65	1.71	70.59	0.69	4.00
28	*Cyclea peltata*	17.65	1.71	27.06	0.26	1.53
29	*Dalbergia lanceolaria*	10.59	1.03	15.29	0.15	1.44
30	*Dendrocalamus strictus*	18.82	1.83	58.82	0.57	3.13
31	*Desmodium heterocarpon*	2.35	0.23	8.24	0.08	3.50
32	*Desmodium laxiflorum*	7.06	0.68	11.76	0.11	1.67
33	*Desmodium pulchellum*	5.88	0.57	7.06	0.07	1.20
34	*Diospyros melanoxylon*	7.06	0.68	9.41	0.09	1.33
35	*Elaeagnus kologa*	2.35	0.23	4.71	0.05	2.00
36	*Elaeocarpus variabilis*	1.18	0.11	1.18	0.01	1.00
37	*Elephantopus scaber*	14.12	1.37	142.35	1.39	10.08
38	*Eleutheranthera ruderalis*	7.06	0.68	31.76	0.31	4.50
39	*Flacourtia indica*	11.76	1.14	14.12	0.14	1.20
40	*Glycosmis pentaphylla*	36.47	3.54	338.82	3.30	9.29
41	*Gmelina arborea*	2.35	0.23	2.35	0.02	1.00
42	*Grewia tiliifolia*	14.12	1.37	20.00	0.19	1.42
43	*Haldina cordifolia*	5.88	0.57	9.41	0.09	1.60
44	*Helicteres isora*	27.06	2.63	50.59	0.49	1.87
45	*Hemidesmus indicus*	1.18	0.11	3.53	0.03	3.00
46	*Hydnocarpus pentandra*	5.88	0.57	5.88	0.06	1.00
47	*Hyptis suaveolens*	3.53	0.34	24.71	0.24	7.00
48	*Lagerstroemia microcarpa*	31.76	3.08	38.82	0.38	1.22
49	*Lagerstroemia speciosa*	3.53	0.34	3.53	0.03	1.00

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50	*Lannea coromandelica*	2.35	0.23	2.35	0.02	1.00
51	*Lantana camara*	54.12	5.25	532.94	5.19	9.85
52	*Lepidagathis incurva*	15.29	1.48	29.41	0.29	1.92
53	*Leucaena leucocephala*	1.18	0.11	1.18	0.01	1.00
54	*Leucas asper*	1.18	0.11	2.35	0.02	2.00
55	*Lindernia crustacea*	12.94	1.26	35.29	0.34	2.73
56	*Mangifera indica*	4.71	0.46	11.76	0.11	2.50
57	*Melastoma malabathricum*	1.18	0.11	1.18	0.01	1.00
58	*Melia azedarach*	4.71	0.46	5.88	0.06	1.25
59	*Melia dubia*	4.71	0.46	4.71	0.05	1.00
60	*Miliusa tomentosa*	1.18	0.11	2.35	0.02	2.00
61	*Mimosa pudica*	48.24	4.68	149.41	1.46	3.10
62	*Mimusops elengi*	2.35	0.23	2.35	0.02	1.00
63	*Mitracarpus hirtus*	9.41	0.91	195.29	1.90	20.75
64	*Naringi crenulata*	20.00	1.94	40.00	0.39	2.00
65	*Olea dioica*	30.59	2.97	80.00	0.78	2.62
66	*Osbeckia aspera*	1.18	0.11	1.18	0.01	1.00
67	*Persea macrantha*	22.35	2.17	40.00	0.39	1.79
68	*Phyllanthus emblica*	2.35	0.23	2.35	0.02	1.00
69	*Piper nigrum*	7.06	0.68	11.76	0.11	1.67
70	*Pongamia pinnata*	5.88	0.57	8.24	0.08	1.40
71	*Premna mollissima*	1.18	0.11	1.18	0.01	1.00
72	*Pterocarpus marsupium*	8.24	0.80	8.24	0.08	1.00
73	*Rauvolfia serpentina*	3.53	0.34	5.88	0.06	1.67
74	*Schleichera oleosa*	16.47	1.60	22.35	0.22	1.36
75	*Schrebera swietenioides*	1.18	0.11	1.18	0.01	1.00
76	*Senna spectabilis*	10.59	1.03	188.24	1.83	17.78
77	*Senna tora*	3.53	0.34	10.59	0.10	3.00
78	*Shorea roxburghii*	15.29	1.48	36.47	0.36	2.38
79	*Sida acuta*	3.53	0.34	3.53	0.03	1.00
80	*Sida alnifolia*	11.76	1.14	22.35	0.22	1.90
81	*Solanum aculeatissimum*	18.82	1.83	29.41	0.29	1.56
82	*Spathodea campanulata*	11.76	1.14	18.82	0.18	1.60
83	*Stachyphrynium jamaicensis*	3.53	0.34	110.59	1.08	31.33
84	*Streblus asper*	7.06	0.68	7.06	0.07	1.00
85	*Syzygium cumini var. cumini*	18.82	1.83	60.00	0.58	3.19
86	*Tabernamontana alternifolia*	16.47	1.60	32.94	0.32	2.00
87	*Tamilnadia ulginosa*	1.18	0.11	1.18	0.01	1.00

88	*Tectona grandis*	20.00	1.94	42.35	0.41	2.12
89	*Terminalia bellirica*	5.88	0.57	5.88	0.06	1.00
90	*Terminalia cuneata*	3.53	0.34	3.53	0.03	1.00
91	*Terminalia elliptica*	50.59	4.91	72.94	0.71	1.44
92	*Terminalia paniculata*	14.12	1.37	14.12	0.14	1.00
93	*Triumfetta rhomboidea*	4.71	0.46	4.71	0.05	1.00
94	*Vitex altissima*	4.71	0.46	5.88	0.06	1.25
95	*Ziziphus glabrata*	20.00	1.94	20.00	0.19	1.00
96	*Ziziphus oenoplia*	5.88	0.57	7.06	0.07	1.20
	Total	**1029.41**	**99.89**	**8228.24**	**80.18**	**368.08**

Table 11. Phytosociological analysis of vegetation in Vayal

Sl no	**Species**	**F**	**RF (%)**	**D (Individuals/ha)**	**RD**	**A**
1	*Ageratum conyzoides*	10.59	1.03	768.24	2.39	72.56
2	*Annona squamosa*	1.18	0.11	22.35	0.07	19.00
3	*Anogeissus latifolia*	11.76	1.15	11.76	0.04	1.00
4	*Arundinella leptochloa*	83.53	8.16	11662.35	36.27	139.62
5	*Axonopus compressus*	17.65	1.72	2917.65	9.07	165.33
6	*Bauhinia malabarica*	1.18	0.11	1.18	0.00	1.00
7	*Biophytum reinwardtii var reinwardtii*	4.71	0.46	4.71	0.01	1.00
8	*Butea monosperma*	2.35	0.23	2.35	0.01	1.00
9	*Calotropis gigantea*	3.53	0.34	3.53	0.01	1.00
10	*Careya arborea*	4.71	0.46	4.71	0.01	1.00
11	*Cassia fistula*	12.94	1.26	20.00	0.06	1.55
12	*Catunaregam spinosa*	4.71	0.46	4.71	0.01	1.00
13	*Chonemorpha fragrans*	1.18	0.11	1.18	0.00	1.00
14	*Crassocephalum crepidioides*	40.00	3.91	80.00	0.25	2.00
15	*Curculigo orchioides*	7.06	0.69	11.76	0.04	1.67
16	*Curcuma neilgherrensis*	23.53	2.30	49.41	0.15	2.10
17	*Cyperus pilosus*	8.24	0.80	195.29	0.61	23.71

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

18	*Cyperus pilosus*	8.24	0.80	195.29	0.61	23.71
19	*Dalbergia latifolia*	4.71	0.46	4.71	0.01	1.00
20	*Dendrocalamus strictus*	7.06	0.69	11.76	0.04	1.67
21	*Desmodium trifolium*	15.29	1.49	712.94	2.22	46.62
22	*Digitaria ciliaris*	29.41	2.87	992.94	3.09	33.76
23	*Elephantopus scaber*	8.24	0.80	37.65	0.12	4.57
24	*Eleutheranthera ruderalis*	4.71	0.46	37.65	0.12	8.00
25	*Eragrostis tenella*	21.18	2.07	1052.94	3.27	49.72
26	*Eucalyptus globulus*	1.18	0.11	3.53	0.01	3.00
27	*Flemingia strobilifera*	2.35	0.23	7.06	0.02	3.00
28	*Glycosmis pentaphylla*	14.12	1.38	148.24	0.46	10.50
29	*Grangea maderaspatana*	7.06	0.69	11.76	0.04	1.67
30	*Haldina cordifolia*	35.29	3.45	38.82	0.12	1.10
31	*Hemidesmus indicus*	3.53	0.34	8.24	0.03	2.33
32	*Jansenella griffithiana*	18.82	1.84	203.53	0.63	10.81
33	*Kyllinga nemoralis*	24.71	2.41	4289.41	13.34	173.62
34	*Lagerstroemia microcarpa*	8.24	0.80	8.24	0.03	1.00
35	*Lannea coromandelica*	1.18	0.11	1.18	0.00	1.00
36	*Lantana camara*	43.53	4.25	423.53	1.32	9.73
37	*Lepidagathis incurve*	1.18	0.11	3.53	0.01	3.00
38	*Leucas asper*	8.24	0.80	10.59	0.03	1.29
39	*Ludwigia peruviana*	1.18	0.11	7.06	0.02	6.00
40	*Melastoma malabathricum*	2.35	0.23	12.94	0.04	5.50
41	*Mimosa pudica*	52.94	5.17	172.94	0.54	3.27
42	*Mitracarpus hirtus*	18.82	1.84	137.65	0.43	7.31
43	*Naringi crenulata*	2.35	0.23	2.35	0.01	1.00
44	*Olea dioica*	7.06	0.69	8.24	0.03	1.17
45	*Panicum trypheron*	29.41	2.87	736.47	2.29	25.04
46	*Phyllanthus emblica*	4.71	0.46	4.71	0.01	1.00
47	*Pterocarpus marsupium*	5.88	0.57	9.41	0.03	1.60
48	*Rhynchospora corymbosa*	7.06	0.69	81.18	0.25	11.50
49	*Sacciolepis indica*	30.59	2.99	250.59	0.78	8.19
51	*Senna tora*	21.18	2.07	45.88	0.14	2.17
52	*Shorea roxburghii*	3.53	0.34	8.24	0.03	2.33
53	*Sida acuta*	10.59	1.03	18.82	0.06	1.78
54	*Sida alnifolia*	16.47	1.61	25.88	0.08	1.57
55	*Solanum aculeatissimum*	29.41	2.87	54.12	0.17	1.84
56	*Sporobolus tenuissimus*	56.47	5.52	632.94	1.97	11.21

57	*Syzygium cumini var. cumini*	18.82	1.84	21.18	0.07	1.13
58	*Tabernamontana alternifolia*	2.35	0.23	2.35	0.01	1.00
59	*Tamilnadia uliginosa*	18.82	1.84	20.00	0.06	1.06
60	*Tectona grandis*	16.47	1.61	41.18	0.13	2.50
61	*Terminalia bellirica*	4.71	0.46	4.71	0.01	1.00
62	*Terminalia cuneata*	7.06	0.69	7.06	0.02	1.00
63	*Terminalia elliptica*	48.24	4.71	74.12	0.23	1.54
64	*Themeda triandra*	8.24	0.80	105.88	0.33	12.86
65	*Trewia nudiflora*	1.18	0.11	2.35	0.01	2.00
66	*Ziziphus oenoplia*	2.35	0.23	3.53	0.01	1.50
	Total	**1023.53**	**100**	**32156.47**	**100**	**997.96**

In NF, highest Simpson diversity index was obtained in control (0.96) plots and lowest was in 'CS' plots (0.35) (Table 12). It means that control plots are more diverse than any other weed category areas in NF. Highest Berger-Parker dominance was obtained for 'CS' plots (0.81) and lowest was seen in control plots (0.07). Highest Margalef richness was seen in control plots (5.16) and lowest was in 'CS' plots (0.83). Pielou's equitability index was highest in 'control' plots (0.96), which imply that all individuals in 'control' plots are evenly distributed. Among the three IAPS, S plots had the minimum diversity and species richness.

In plantation, highest Simpson diversity index was obtained in control plots (0.92), which means that control plots are the most diverse region in plantation (Table 13). The lowest Simpson diversity index was in 'S' plots (0.56). This implies that *Senna* affected regions are the least diverse region in plantation. It is the control plots (0.23) which have the lowest Berger-Parker dominance index. The 'S' plots has the highest Berger-Parker index (0.66). Margalef richness index was highest in control plots (5.2) and minimum was in 'S' plots (0.91). The control plots and 'L' plots has almost similar Pielou's equitability index in plantation. Lowest Pielou's equitability index was obtained in 'S' plots (0.77). Among the three IAPS, minimum species richness in plantation was in S plots. It was followed by C and L plots.

In vayal, highest Simpson diversity index was seen in control plots (0.82) and the lowest was in 'C' plots (Table 14). This implies that control plots are diverse than any other weed category areas in vayal. Highest dominance was observed in 'C' plots (0.87) and lowest was in control plots (0.25). It is the control plots that shows highest Margalef richness index. The control plot in vayal has the highest Pielou's equitability index which means that all individuals in vayal are evenly distributed. Among the three IAPS, minimum species richness and diversity was in C plots. It was followed by L plots.

Table 12. 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
C	0.73	0.55	1.82	0.8
L	0.81	0.41	2.01	0.85
S	0.62	0.63	1.66	0.72
LC	0.78	0.5	2.17	0.83
CS	0.35	0.81	0.83	0.54
LCS	0.87	0.29	2.47	0.89
CONTROL	0.96	0.07	5.16	0.96

Table 13. 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
C	0.65	0.6	1.3	0.78
L	0.86	0.27	2.45	0.89
S	0.56	0.66	0.91	0.77
LC	0.76	0.44	1.82	0.82
LCS	0.71	0.45	1.25	0.84
CONTROL	0.92	0.23	5.2	0.88

Table 14. 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
C	0.23	0.87	0.69	0.34
L	0.61	0.59	1.57	0.55
LC	0.49	0.63	0.83	0.48
CONTROL	0.82	0.25	3.62	0.64

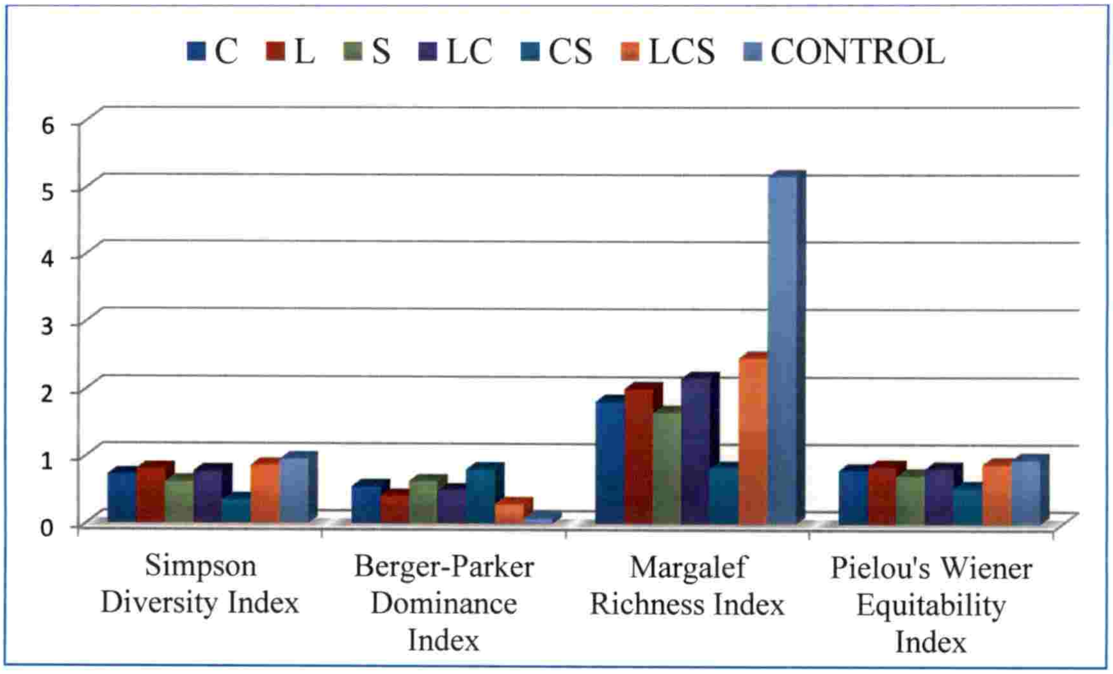

Figure 12. Phytosociological analysis of weed category areas in NF

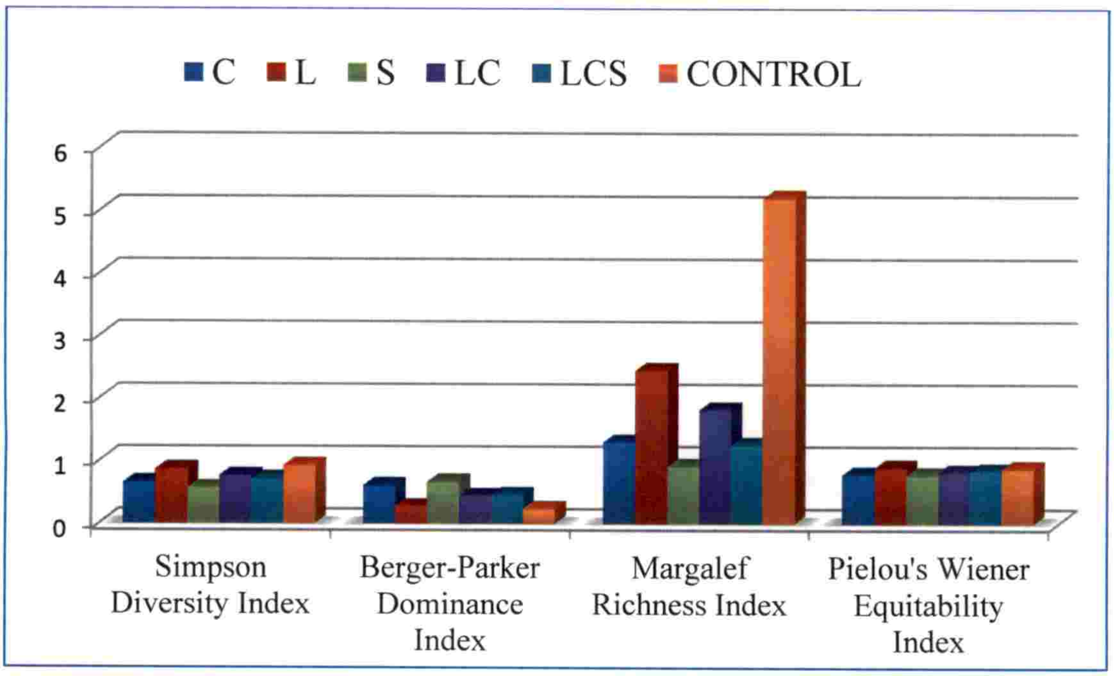

Figure 13. Phytosociological analysis of weed category areas in Plantation

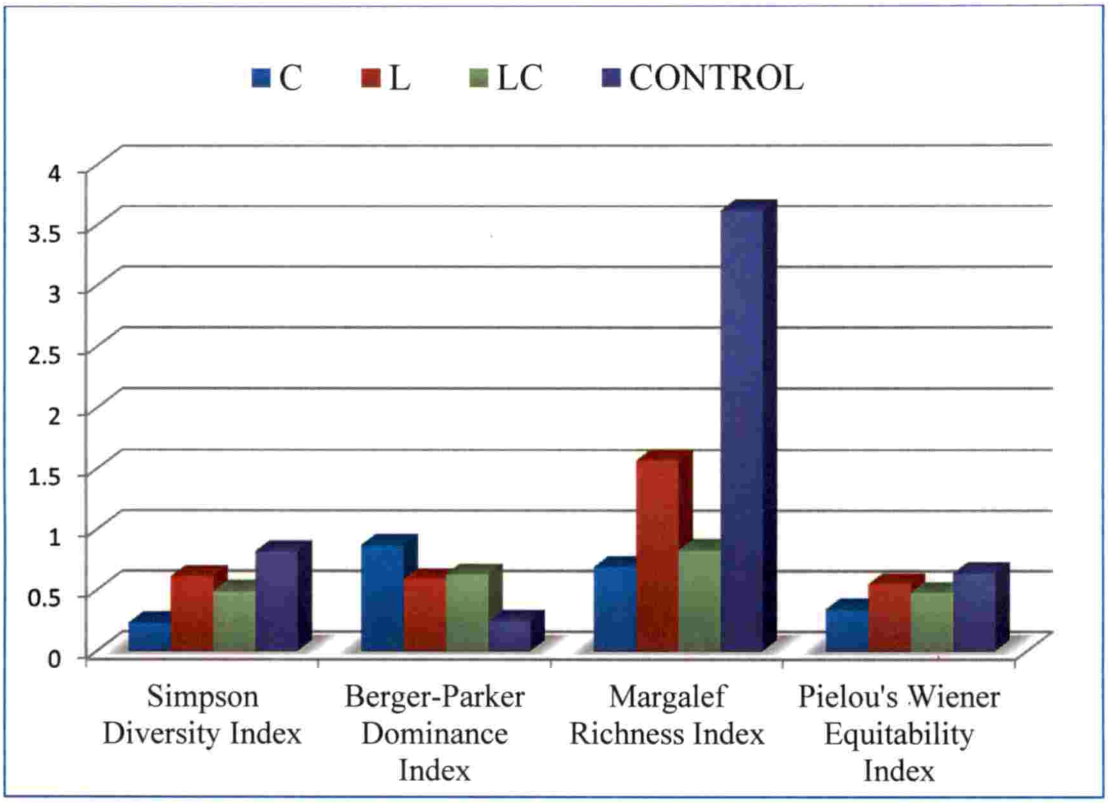

Figure 14. Phytosociological analysis of weed category areas in Vayal

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

The species richness of native species in each vegetation type was regressed against the percentage cover of *L. camara, C. odorata and S. spectabilis*. The models in each vegetation types were highly significant. Regression equations were made for each vegetation types (Table 15). Significance of regression coefficients were tested using anova (<0.001). The models were highly significant. All the three IAPS decreased the native species richness.

The regression model in NF explained that, about 0.38% variation was observed in native species richness due to the three IAPS (Table 15). In plantation and vayal the variation was 0.3% and 0.31% respectively. All the three IAPS negatively influenced the species richness of native plants (Fig. 15). From the Standardized Partial Regression Coefficients (SPRC) equation it can be seen that in NF, *C. odorata* (0.55) had the primary influence on species richness of native species followed by *S. spectabilis* (0.35) and *L. camara* (0.33). In plantation both *L. camara* (0.40) and *C. odorata* (0.41) has almost similar influence on native species richness (Table 16). In vayal *C. odorata* (0.54) has highest influence on species richness followed by *L. camara* (0.18) (Table 17).

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Table 15. 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 *L. camara* (X_1)	$Y=14.1-0.15X_1-0.16X_2-0.10X_3$	0.15	0.16	0.1	14.11
	Percentage cover of *C. odorata* (X_2)					
	Percentage cover of *S. Spectabilis* (X_3)					

Table 16. Multiple regression equation in plantation

Dependent variable	Independent variable	Equation	X_1	X_2	X_3	Intercept
Native species richness (Y)	Percentage cover of *L. camara* (X_1)	$Y= 10.46-0.12X_1-0.15 X_2 -0.04X_3$	0.12	0.15	0.04	10.46
	Percentage cover of *C. odorata* (X_2)					
	Percentage cover of *S. Spectabilis* (X_3)					

Table 17. Multiple regression equation in vayal

Dependent variable	Independent variable	Equation	X_1	X_2	X_3	Intercept
Native species richness (Y)	Percentage cover of *L. camara* (X_1)	$Y= 11.07-0.29X_1-0.14 X_2$	0.29	0.14	0.04	11.07
	Percentage cover of *C. odorata* (X_2)					

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Table 18. 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*	−0.16 ± 0.04	-0.55	<0.001	0.38
	Percentage cover of *L. camara*	− 0.15 ± 0.02	-0.33	<0.001	
	Percentage cover of *S. spectabilis*	− 0.10 ± 0.03	-0.35	<0.001	

Table 19. 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*	−0.15 ± 0.03	-0.41	<0.001	0.3
	Percentage cover of *L. camara*	−0.12 ± 0.03	-0.4	<0.002	
	Percentage cover of *S. spectabilis*	− 0.06 ± 0.02	-0.27	<0.003	

Table 20. 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*	−0.14 ± 0.02	0.54	<0.001	0.31
	Percentage cover of *L. camara*	−0.19 ± 0.1	-0.18	<0.002	

(SPRC: Standardized partial regression coefficient)

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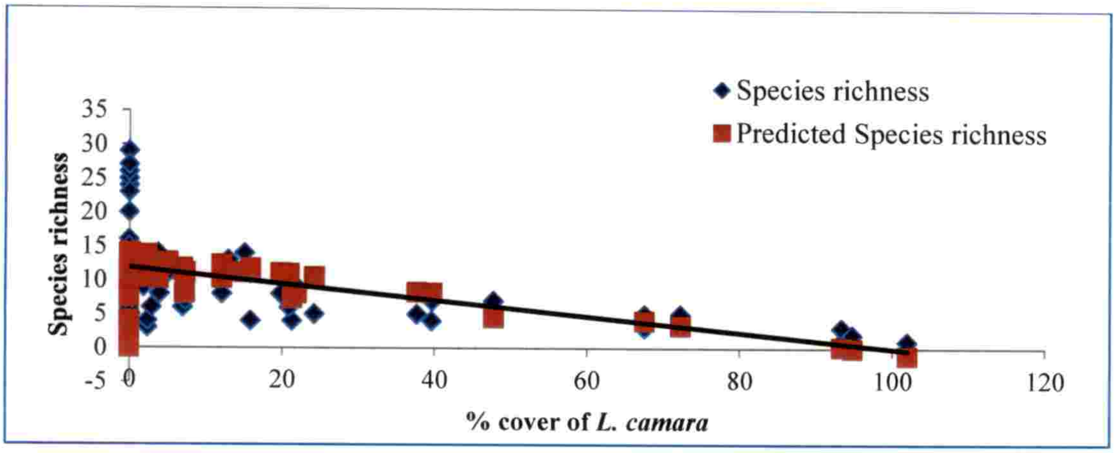
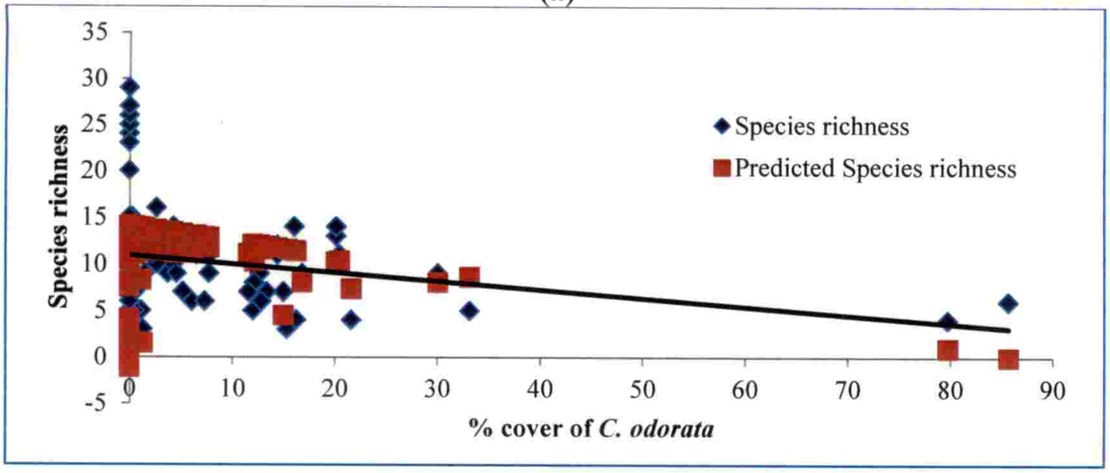


(a)



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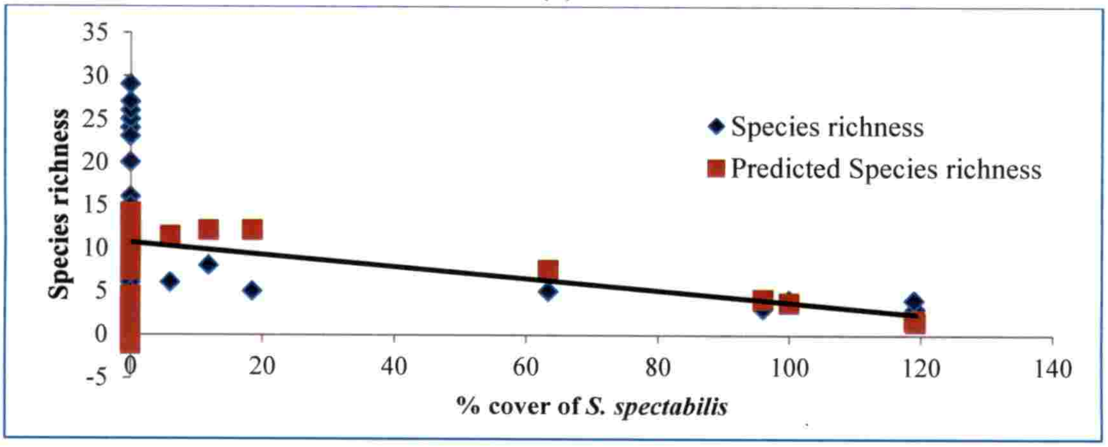
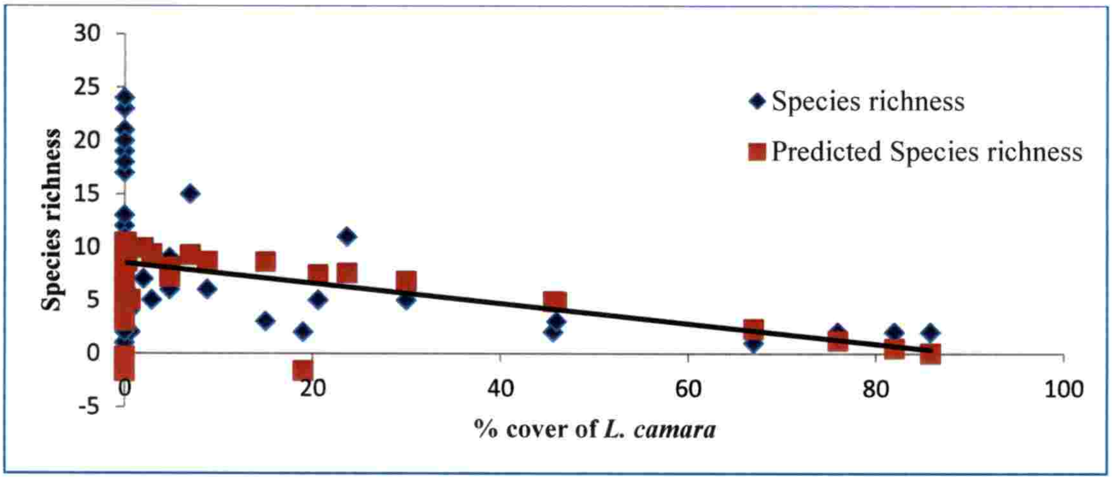


(c)

Figure 15. Actual and predicted relationship between species richness and percentage cover *of L. camara* (a), *C. odorata* (b) and *S. spectabilis* (c) in NF.



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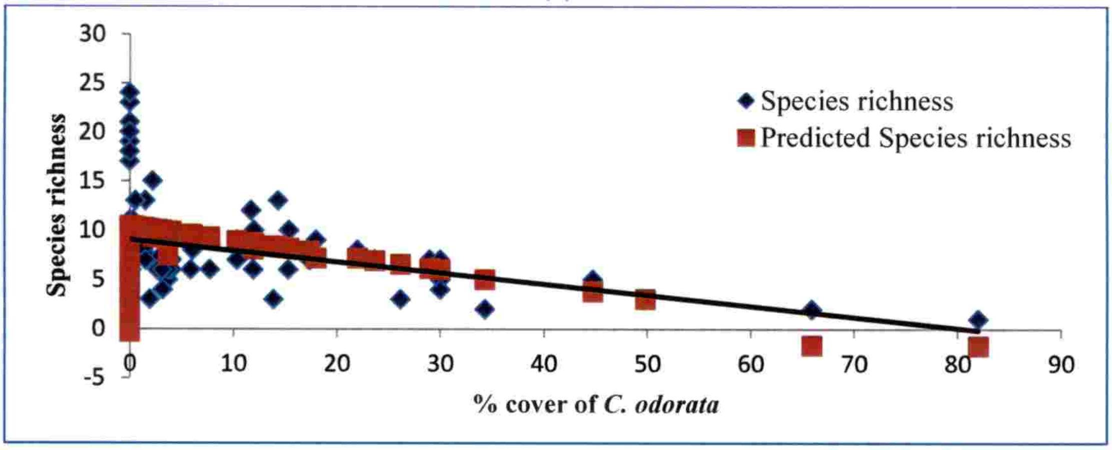

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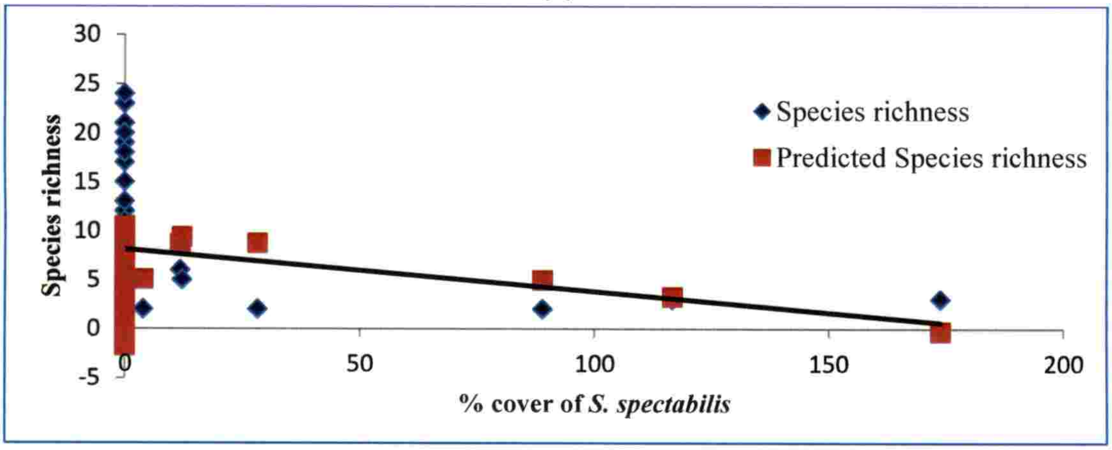
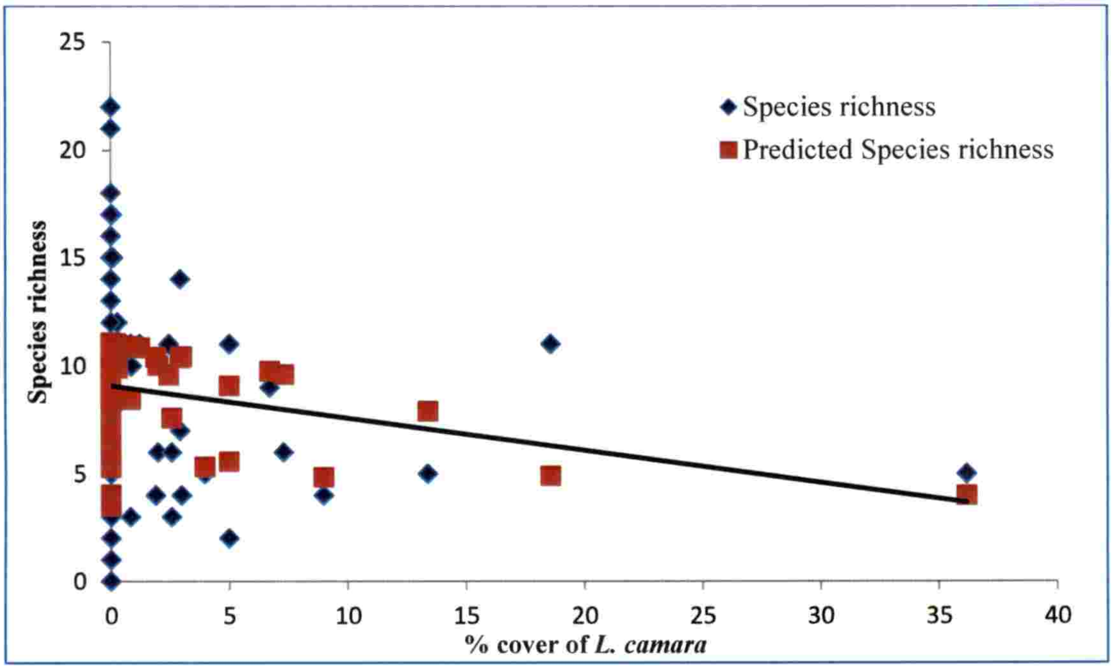
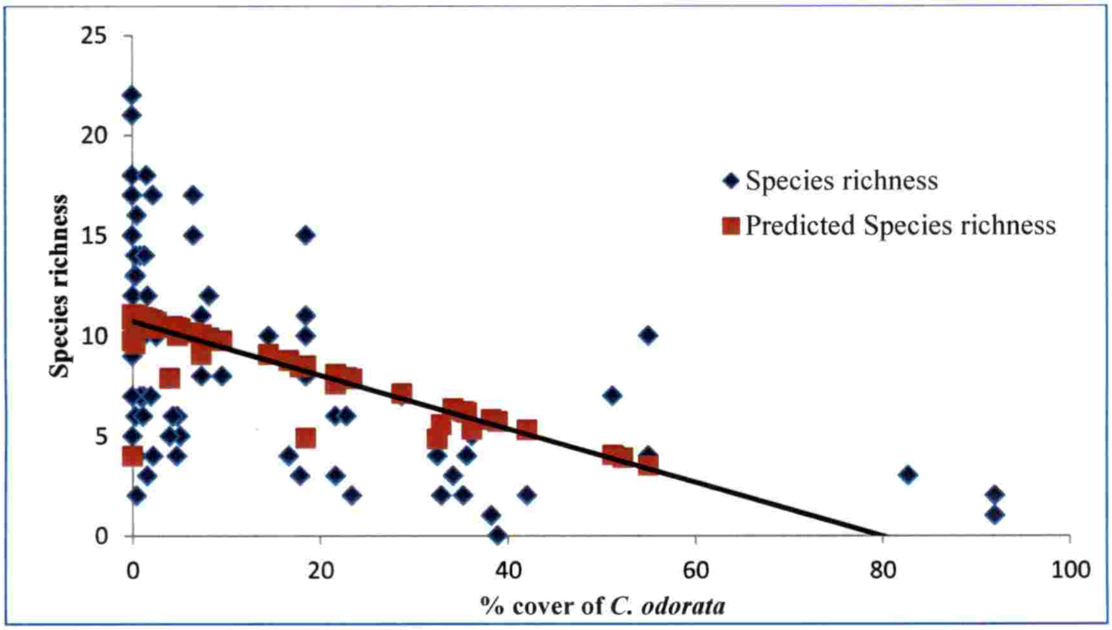


(c)

Figure 16. Actual and predicted relationship between species richness and percentage cover *of L. camara* (a), *C. odorata* (b) and *S. spectabilis* (c) in Plantation.



(a)



(b)

Fig.17. Actual and predicted relationship between species richness and percentage cover *of L. camara* (a) and *C. odorata* (b) in Vayal.

4.4.4 Influence of percentage cover of IAPS on species richness of different growth forms of native species

Linear regressions models were worked out for finding the changes in species richness of native species (herb, shrub, tree and climber) in response to percentage cover of *Lantana, Chromolaena* and *Senna.* Each of the four growth forms (herbs, shrubs, climbers) other than trees showed a significant decline in species richness due to the percentage cover of *L. camara, C. odorata* and *S. spectabilis* (Table 21).

The herbaceous species richness declined with increased *C. odorata* percentage cover in NF (Fig. 18). The model was highly significant and for every 10% increase in *Chromolaena* cover, two native herb species was removed from the study area. The actual herb species richness was so closer to the predicted species richness. The R^2 value of the model was 0.96. The shrub species richness also decreased due to increase in *Chromolaena* cover. The R^2 value of the model was 0.62.

The increase in percentage cover of *L. camara* decreased the herb species richness. The actual species richness of herb species was very closer to predicted species richness. For every 20% increase in *Lantana* cover, two herb species were removed (Fig. 18). Similar observations were obtained for shrubs also. For every 20% increase in *Lantana* cover, one shrub species was removed from the study area. The species richness of trees didn't show any significant variation with *Lantana* cover. The actual species richness of trees was far from predicted species richness. On plotting herb species richness against *Senna* percentage cover, it was found that there was only four herb species obtained from 50% of *Senna* affected area (Fig. 19). On further increase in percentage cover of *Senna* the herb species richness declined linearly and it was decreased to one at 100% *Senna* cover. There was only two shrub species obtained from *Senna* affected area. By the increase of *Senna* cover to 100%, there was no shrub species obtained from study area. But there was one herb species

(*Mimosa pudica*) located at 100% of *Senna* cover. When *Lantana* and *Chromolaena* was together present, the variation in herb species richness was linear (Fig. 19). For every 10% increase in weed cover, one herb species was removed. Similar variation was obtained in shrubs also. Every 10% increased weed cover remove one native shrub species from natural forest.

Table 21. Linear regression analyses for native (herb, shrub, tree and climber) species richness against percentage cover of IAPS in NF

	Linear
L	
No of native herb species	
R2	0.96
P	<0.001
Residual error	10.25
No of native shrub species	
R2	0.89
P	<0.001
Residual error	3.7
No of native tree species	
R2	0.09
P	0.23
Residual error	17.96
C	
No of native herb species	
R2	0.96
P	<0.0001
Residual error	14.51
No of native shrub species	
R2	0.61
P	<0.0001
Residual error	26.96

	Linear
C	
No. of tree species	
R2	0.14
P	0.09
Residual error	18.1
No. of climber species	
R2	0.04
P	0.33
Residual error	17.76
S	
No of native herb species	
R2	0.91
P	0.04
Residual error	0.44
No of native shrub species	
R2	0.96
P	0.01
Residual error	0.06
No of native tree species	
R2	0.01
P	0.8
Residual error	2.7

LC	
No of native herb species	
R2	0.4
P	<0.001
Residual error	55.38
No of native shrub species	
R2	0.36
P	<0.001
Residual error	71.44

LC	
No of native tree species	
R2	0.1
P	0.11
Residual error	26.4
No of native climber species	
R2	0.08
P	0.15
Residual error	6.92

In plantation species richness of herb and shrubs varied linearly with *Lantana* cover (Fig. 20). The R^2 value of the model was lesser than 0.50 (Table 19) and also the actual species richness (SR) was not near to the predicted SR. So the model formed can't be fitted. Regression analysis for *Chromolaena* and shrub species showed high significance. The R^2 value of the model was high (0.80), which mean that the model can be fitted. For every 10% increase in crown cover of *Chromolaena*, one native herb species was removed from the plantation. On further increase of percentage cover the species richness was decreased to zero. As similar to herbs, one native shrub species was removed at every 20% increase in *Chromolaena* cover. Regression analysis for *Senna* and plant growth forms (herbs, shrubs, trees and climber) showed no significance. When both of the weeds *Lantana* and *Chromolaena* (LC) were present there was significant decline in herb species richness. At 40% weed cover, there were 10 native herb species; it was reduced to 8 at next 40% weed cover (Fig 20). The lowest R^2 value (0.38) for herb species in LC indicated that the equation formed was not good (Table 19). For shrub species also the R^2 value was lower. So there was no specific pattern was observed for shrub SR. Climbers also showed significant reduction in SR with increasing LC cover (Fig. 20). When all the three weed species *Lantana*, *Chromolaena* and *Senna* were occurred together, there was significant reduction in herb SR. The R^2 value of the relation was higher (0.99) which mean that the model showed good fitting.

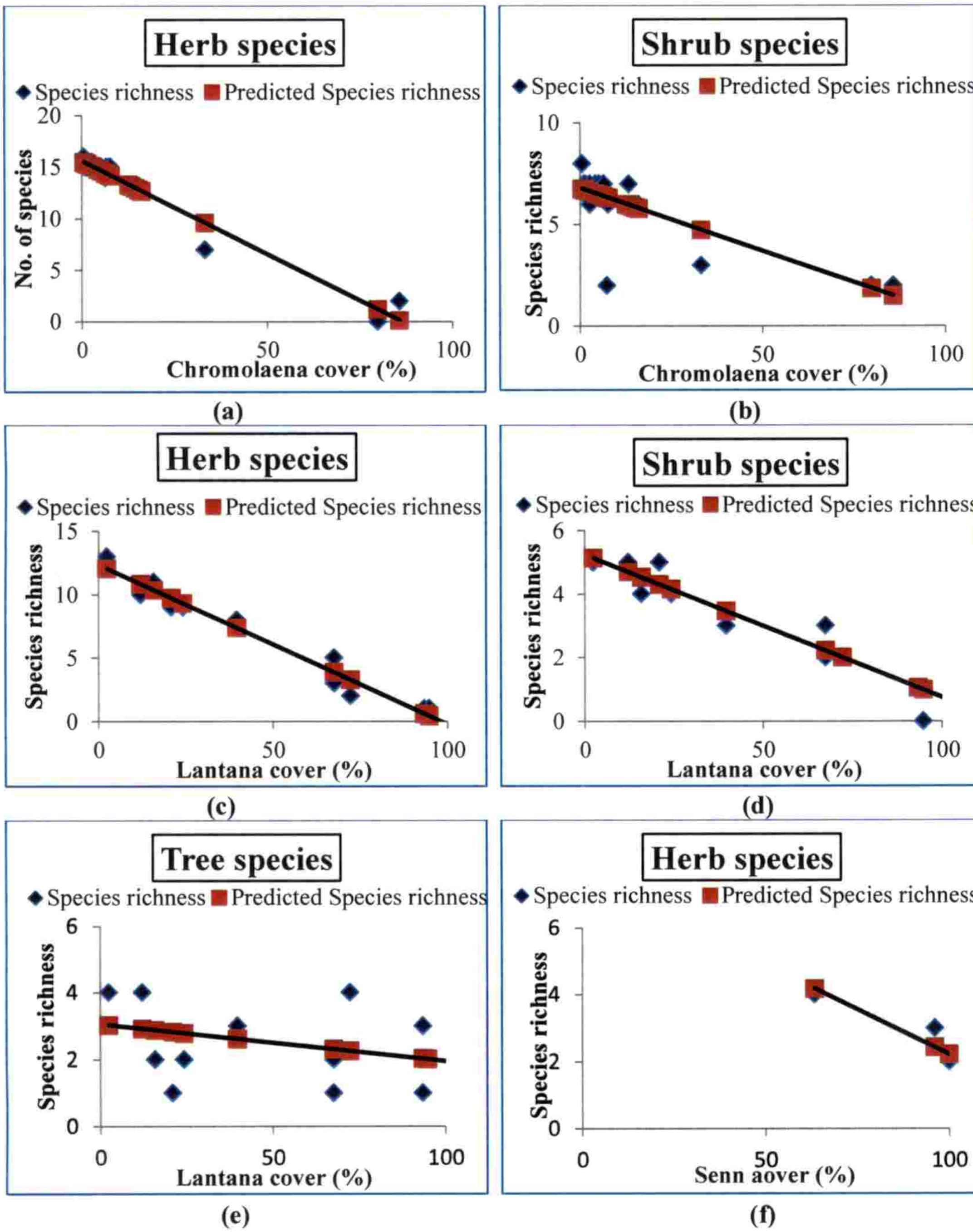
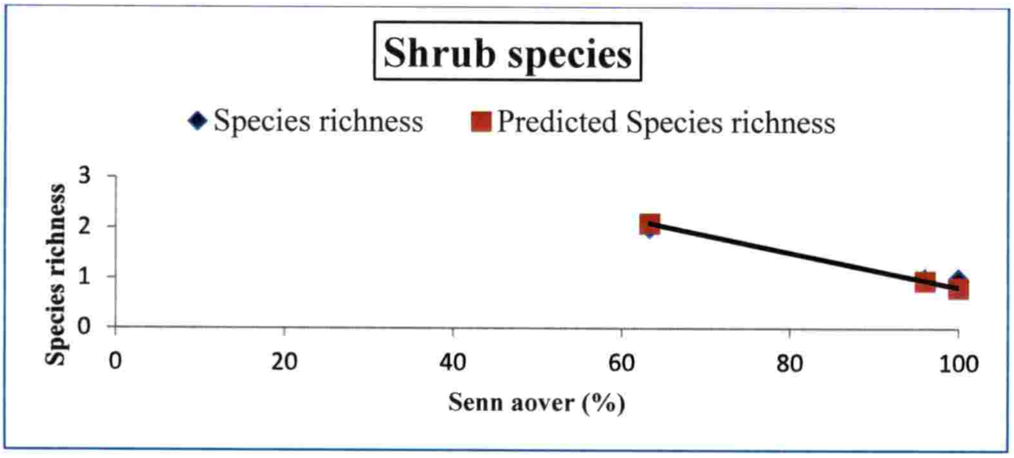


Figure 18. Relationships between Chromolaena and Lantana cover (%) and native herb species richness and native shrubs species richness in NF. (a) & (b) are Chromolaena affected plots. (c), (d), (e) are Lantana affected plots. (f) Senna affected plots.



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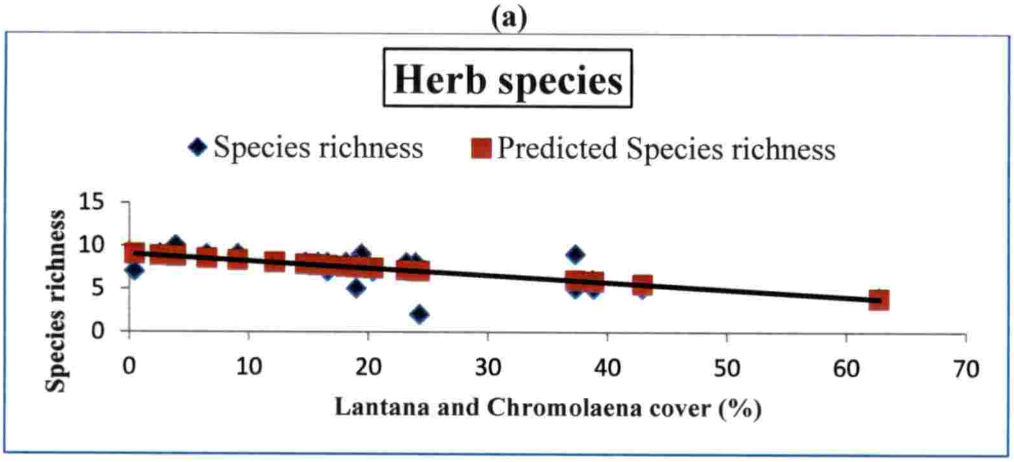

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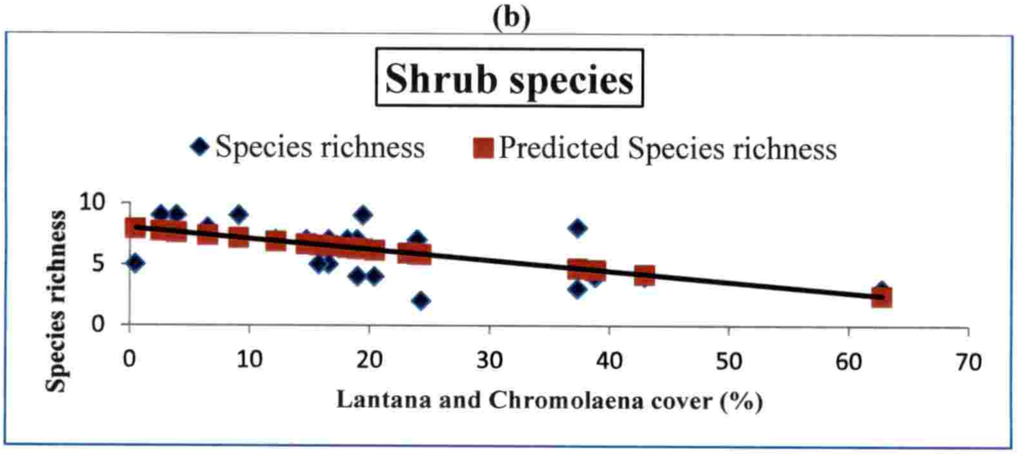

(c)

Figure 19. Relationships between Chromolaena, Lantana and Senna cover (%) and native herb species richness and native shrubs species richness in NF. (a) Senna affected plot, (b) & (c) Lantana and Chromolaena affected plots.

Table 22. Linear regression analyses for native (herb, shrub, tree and climber) species richness against percentage cover of IAPS in plantation

	Linear
L	
Number of native herb species	
R Square	0.41
p value	0.03
Residual Error	23.75
Number of native shrub species	
R Square	0.41
p value	0.04
Residual Error	9.50
Number of native tree species	
R Square	0.04
p value	0.56
Residual Error	4.37
Number of native climber species	
R Square	0.09
p value	0.38
Residual Error	0.83
C	
Number of native herb species	
R Square	0.80
p value	<0.0001
Residual Error	45.8
Number of native shrub species	
R Square	0.72
p value	<0.0001
Residual Error	30.87

	Linear
C	
Number of native tree species	
R Square	0.02
p value	0.29
Residual Error	37.52
Number of native climber species	
R Square	0.08
p value	0.05
Residual Error	10.52
Number of native climber species	
R Square	0.08
p value	0.05
Residual Error	10.52
S	
Number of native herb species	
R Square	0.81
p value	0.09
Residual Error	1.87
Number of native shrub species	
R Square	0.57
p value	0.24
Residual Error	1.20
Number of native tree species	
R Square	0.30
p value	0.45
Residual Error	0.52

LC	
No of native herb species	
R2	0.38
P	0.04
Residual error	160
No of native shrub species	
R2	0.48
P	0.01
Residual error	24.45
Number of native tree species	
R Square	0.08
p value	0.4
Residual Error	23.66
Number of native climber species	
R Square	0.44
p value	0.02
Residual Error	1.43

LCS	
No of native herb species	
R2	1.00
P	0.01
Residual error	0.003
Number of native shrub species	
R Square	0.99
p value	0.07
Residual Error	0.05
Number of native tree species	
R Square	0.54
Residual Error	0.92
p value	0.47

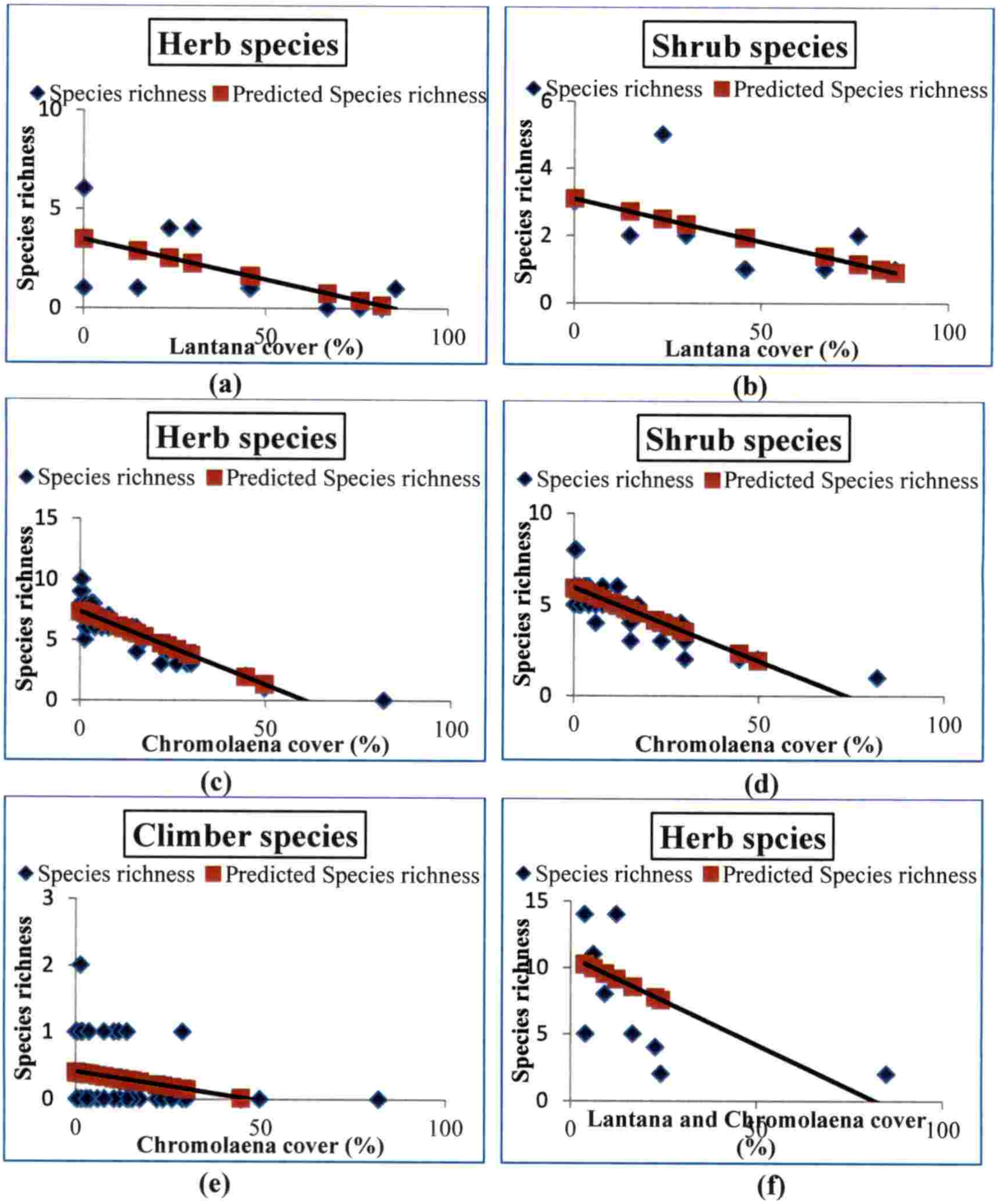

Figure 20. Relationships between Chromolaena and Lantana cover (%) and native herb species richness and native shrubs species richness in plantation. (a) & (b) are Lantana affected plots. (c), (d) & (e) are Chromolaena affected plots. (f) is Lantana and Chromolaena affected plot.

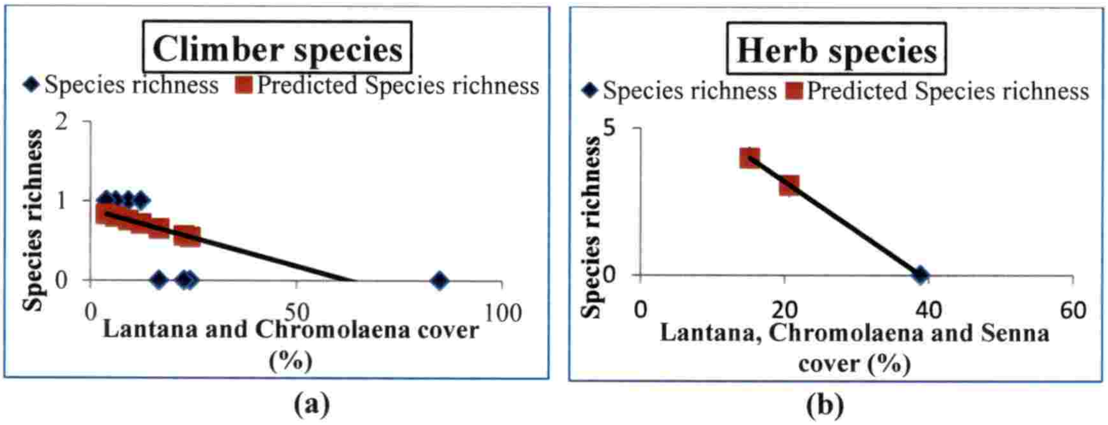

Figure 21. Relationships between Chromolaena and Lantana cover (%) and native herb species richness and native shrubs species richness in plantation. (a) & (b) are Lantana affected plots. (c), (d) & (e) are Chromolaena affected plots.

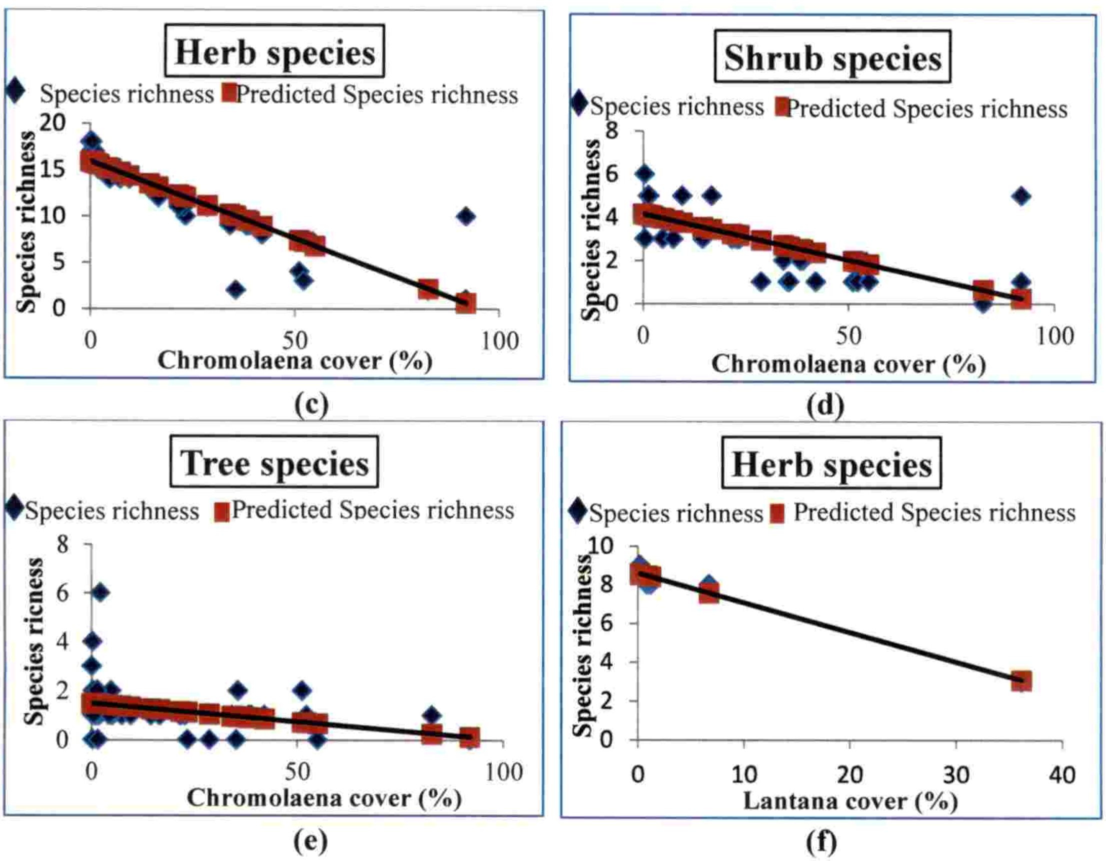

Figure 22. Relationships between Chromolaena, Lantana and Senna cover (%) on native herb species richness and native shrubs species richness in vayal. (a), (b) & (c) are Chromolaena affected plots. (d) Lantana affected plot.

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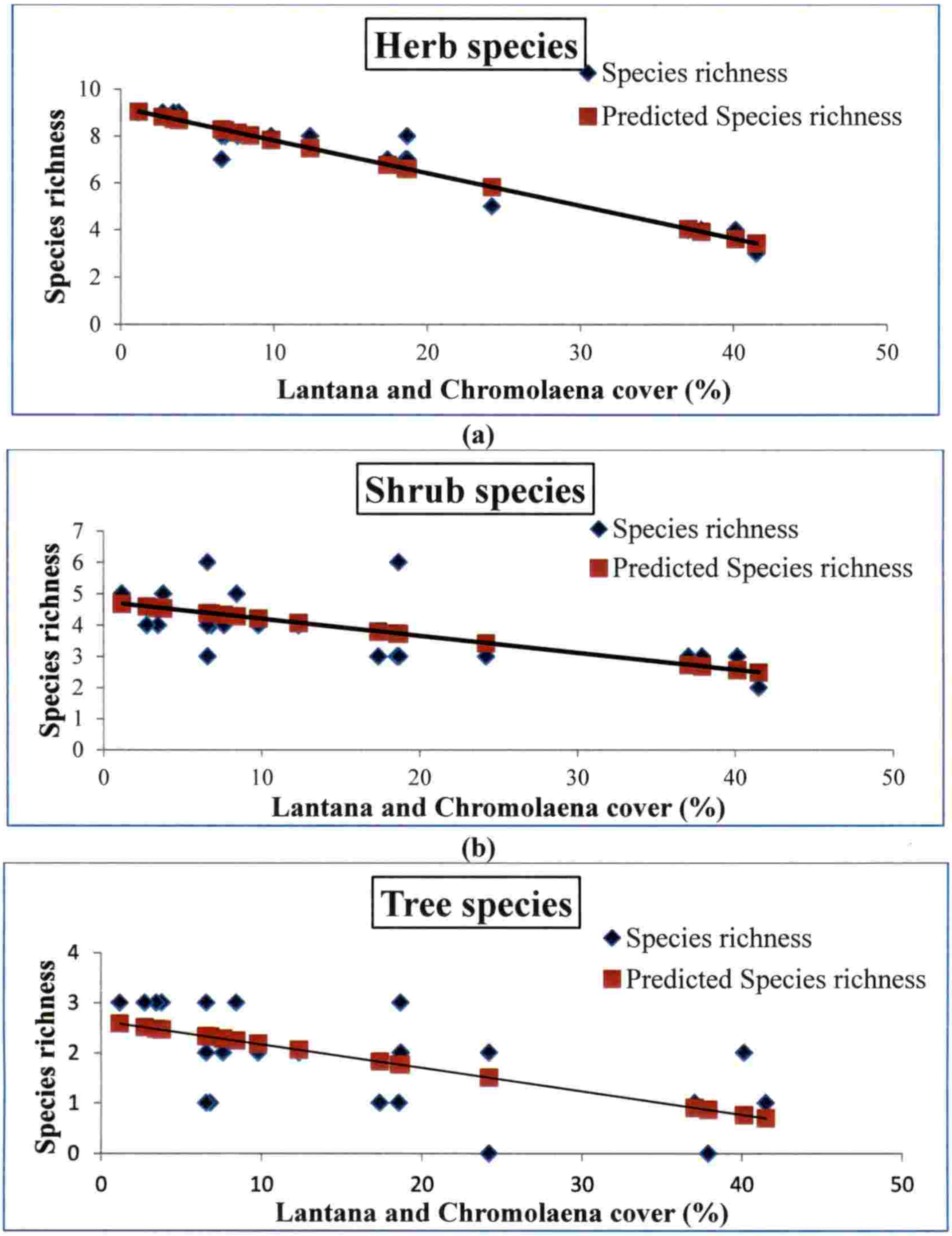
Table 23. Linear regression analyses for native (herb, shrub, tree and climber) species richness against percentage cover of IAPS in vayal

	Linear
L	
No of native herb species	
R2	0.97
P	0.002
Residual error	0.75
No of native shrub species	
R2	0.33
P	0.38
Residual error	7.21
No of native tree species	
R2	0.1
P	0.61
Residual error	1.08
C	
No of native herb species	
R2	0.78
P	<0.001
Residual error	218.57
No of native shrub species	
R2	0.47
P	<0.001
Residual error	60.17

	Linear
C	
No of native tree species	
R2	0.12
P	0.01
Residual error	46.2
No of native climber species	
R2	0.03
P	0.28
Residual error	1.86
LC	
No of native herb species	
R2	0.92
P	<0.001
Residual error	6.62
No of native shrub species	
R2	0.432
P	<0.001
Residual error	15.26
No of native tree species	
R2	0.34
P	<0.001
Residual error	16.26

In vayal, the herbaceous species richness declined significantly with increase in *Chromolaena* cover. For every 10% increase in *Chromolaena* cover two native herb species were removed from study area. Shrubs also showed significant decline in species richness due to *Chromolaena* cover. For every 20% increase in percentage cover one native species was removed from the study area (Fig. 22). *Lantana* cover also reduced the herbaceous species significantly in vayal. The actual and predicted SR was very closer. Every 10% increase in weed cover one herb species was missing from vayal. The tree species also showed significant variation due to *Chromolaena* cover (Fig. 22). The herbaceous species richness declined linearly on increase of weed cover (*Lantana* & *Chromolaena*) (Fig. 23). Every 10% increase in weed cover one herb species were missing from vayal. For every 15% increase in weed cover, removed one native shrub species. The tree species also declined linearly with weed cover (Fig. 23). For every 20% in weed cover, one tree species was missing from vayal.



(c)

Figure 23. Relationships between Chromolaena and Lantana cover (%) on native herb species richness and native shrubs species richness in vayal. (a), (b) & (c) are Lantana and Chromolaena affected plots.

Discussion

DISCUSSION

The results of the study conducted during 2017-2018 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 II) of Wayanad WLS of Kerala is discussed below.

5.1 DISTRIBUTION OF IAPS

5.1.1 *Lantana camara*

L. camara was distributed all over the sanctuary except some parts of Sulthan bathery range (Fig. 5). The high invasion of *L. camara* was seen in the Kurichiat RF (Kurichiat range), Rampur and Alathur RF in Sulthan bathery range and Edathara RF of Muthanga range. Less invasion of *Lantana* was seen in borders of Kurichiat and Sulthan bathery range. The borders of Mudumalai WLS and Mavinahalla RF were also free from *Lantana* invasion.

It was assumed that *L. camara* was introduced to India during 1800's from Sri Lanka. As an ornamental plant, *Lantana* was introduced to National Botanical Garden in Calcutta (Mishra, 2014). In disturbed natural forests, *Lantana* became 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 deaths (Babu *et al.,* 2009). It was observed that *L. camara* growing regions are having constant rainfall (>900 mm) or soil moisture. 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. All these factors are favorable in Wayanad WLS and these may the main reasons for invasiveness of *L. camara*. Bhagwat *et al.* (2012) found that *Lantana* has invaded about 5 mha in Australia, 13 mha in India and 2 mha in South Africa. *Lantana* has invaded more than 13.2 million ha pasture land in India (Singh *et al.,* 1996). The weed has invaded the teak plantations in Tamil Nadu (Clarson and Sudha, 1997), infested Western Ghats (Muniappan *et al.,* 2002).

5.1.2 *Chromolaena odorata*

C. odorata was invaded all parts of WS II. High invasion of *Chromolaena* was found in Kurichiat RF of Kurichiat range, Mavinahalla and Noolpuzha RF of Muthanga range, Kallur and Rampur RF in Sulthan bathery range (Fig. 6). 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 and Mavinahalla RF.

5.1.3 *Senna spectabilis*

Senna invasion is now a major management challenge for forest managers all over the globe. 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). Sathyanarayana and Gnanasekharan (2013) had recently noticed that apart from invading Wayanad WLS, *Senna* displays high potential rapid growth in Sathyamangalam and suburban areas of Coimbatore. 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 occupied 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.

According to the records of the Kerala Forests and Wildlife department, it was in 1986, as part Social forestry's shade tree planting program, 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. First flowering of *Senna* appeared 7 years after planting, the beautiful yellow flowers attracted tourists. After 15 years of planting, these trees attained a GBH of 270 cm. Then it started dispersing seeds and acquired an invasive character within a short time period. In the current study, the density of *Senna* in the plantation areas was 63 trees ha^{-1} and 49 trees ha^{-1} was the density in NF (Table 2).

5.2 IMPACT OF IAPS ON NATIVE PLANT DIVERSITY

According to McKinney and Lockwood (1999), invasive alien species can contribute to "biotic homogenization" where the native biodiversity is suppressed and replaced by widespread invasive species. In natural forests (NF), control plots (those plots without IAPS) were observed to be more diverse than any other weed category areas (Table 12). Control plots (0.96) had the highest Simpson Index of Diversity (D) while the lowest values were recorded in 'CS' plots (0.35). The low values of Simpson index of diversity recorded in *Senna* invaded areas (S, CS and LCS) can be attributed to the invasion of *Senna*, which decreased the diversity in WS II of sanctuary. The reduced species diversity here could probably be due to recruitment limitation mechanisms, which may include allelopathy and resource competition. But published evidences to prove this connection is lacking. The plots under C (0.73) and L (0.81) recorded higher Simpson Index of Diversity, but the plots which had *Senna* with *Chromolaena* recorded lower diversity values (0.35). This probably indicates that *S. spectabilis* invasion perhaps more capable of limiting the recruitment of many resident native species, causing reduced species richness, abundance and altered compositions as compared to *L. camara* and *C. odorata.* Similar observations obtained in the plantations also (Table 13) can be explained on the basis of this

Plate 8. Remaining of first Senna plantation

observation. In the weed-less plots inside plantations too, there were no dominant species as is evident by the low Berger Parker Dominance values (0.23).The higher Equitability Index values also points to the fact that all the species here were also equally distributed (Table 13).

On the other hand, the higher dominance index values recorded for *Lantana* (0.27), *Chromolaena* (0.64) and *Senna* (0.66) in plantation indicates their invasiveness and dominance elsewhere. Compared to *Lantana* areas, *Chromolaena* invaded areas had lower species richness and unequal species distribution (Table 13). From these it can be inferred that in the studied plots located in the natural ecosystem, the impact of *Lantana* in resident plant diversity is low compared to Chromalena. The species richness index value was observed to be least in the case of *Senna* invaded areas (0.91). Among the three IAPS, *Senna* invaded areas had the lowest Simpson diversity index (0.56) and highest Dominance index (0.66) value. This indicates that *S. spectabilis* is 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) and highest Dominance index value were recorded in *Chromolaena* (C) invaded area (Table 14). The Richness index and Equitability index value of C plots were 0.69 and 0.34 respectively; this is the lowest value in vayal. This shows that the species richness in *Chromolaena* invaded areas was low compared to control (3.62) and among them, some species are dominant. The Simpson diversity index and Dominance index value of *Lantana* invaded areas were 0.61 and 0.59 respectively. These values confirm the fact that *Chromolaena* is the most problematic IAPS 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 127 plant species recorded from the WS II part of sanctuary, 99 plant species were present in control plots (weed free). However species like *Aporosa cardiosperma, 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, Vitex altissima, Ziziphus mauritiana* were seen only in control plots. 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).

While assessing the impact of three IAPS (*L. camara, C. odorata* and *S. spectabilis*) in the study area, the highest MSR was found in *Lantana* affected areas. But in plots were *Lantana* and *Chromolaena* occured together, the MSR was lower in C plots compared to L plots. 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. 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.

The least MSR was observed in *Senna* affected 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 was decreased from 86 to 4 (Table 7). In plots where *Senna* occured with *Lantana* and *Chromolaena* species richness declined. 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 WS II of sanctuary (Table 15). 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* reduced the regeneration of native species (Grice, 2006). After *Chromolaena*, it was *L. camara* which had an impact on native species. Murali and Setty (2001) 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. 8). The results obtained were similar to the variation found by Day *et al.* (2003). 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 and Dukes, 2007 found that *Lantana* invasion becomes severe only when the percentage cover (thickets) of *Lantana* is greater than a particular limit. Fensham *et al.* (1994) found a negative correlation between plant species richness and *Lantana* density in a dry rainforest site in north Queensland and Gooden *et al.* (2009) 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 at 0% of *L. camara* cover. For every 10% increase in *Lantana* cover, one native species was removed from the WS II of the sanctuary. This pattern was similar in all the three vegetation types (Fig. 15). In the case of *Chromolaena*, maximum species richness was found at 0% of *C. odorata* cover. For every 10% increase in percentage cover of *Chromolaena* two native species was missing from the study area. Only one native species in plantation and NF was removed at every 20% increase in *Senna* cover.

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 13 plant species out of the 125 plant species identified from the sanctuary, were present in *Senna* invaded area. As already pointed out, *S. spectabilis* (Fig. 7), as of now, has invaded only 5 km^2 of the WS II area. 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.

According to Subramanian *et al.* (2001), the invasion of alien plant species may be affected by habitat disturbances and fire. So the variation in these factors 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.* (2009a). Similar observations were obtained for *C. odorata* and *S. spectabilis.* Allelochemicals present in *Lantana* decrease the vigour of native plants of region and results ultimately poor productivity (Theoharides and Dukes, 2007). The predicted species richness indicated that increase in percentage covers of *L. camara* gradually decreased the species richness of native species (Fig. 15).

Species richness in each growth form (herb & shrub) declined significantly with increasing *Lantana*, *Chromolaena* and *Senna* cover (Table 18). In the present study, trees and climbers did not show significant variation with percentage covers of *Lantana*, *Chromolaena* and *Senna* (Table 18). Since it was one year study, it was nearly impossible to compare the growth of trees in accordance with the weed cover.

The herbaceous species richness declined with increased *C. odorata* percentage cover in NF (Fig. 18). The relation was highly significant and for every 10% increase in *Chromolaena* cover, two native species was removed from the study area. The actual herb species richness was closer to the predicted species richness. The R^2 value of the relation was too high (0.96) which implies that model was good fit. The shrub species richness also decreased due to increase in *Chromolaena* cover. The R^2 value of the relation was 0.62. In vayal, for every 10% increase in *Chromolaena* cover one herb species was missing from vayal (Fig. 22). For every 10% increase in *Chromolaena* cover, one native herb species was removed from the plantation.

The influence of *Chromolaena* on shrub species showed a linear trend. For every 20% increase in *Chromolaena* cover one shrub species was removed from WS II of sanctuary (Fig. 22). Similar observations were seen in vayal also. But in plantation first species was removed only after 40% of *Chromolaena* cover (Fig. 20). There were only one or two shrub species after 30% of *Chromolaena* cover. Previous data showed that the species *Mimosa pudica* and *Glycosmis pentaphylla* were highly resistant to all weed category areas (Table 7).

The influence of *Lantana* on herbaceous species showed a negative linear trend in all the three vegetation types (Table 18). Similar variations were obtained by Gooden *et al.* (2009) in Australia. There were 12 herb species at first 10% of *Lantana* cover and it was decreased to 8 at next 10% of *Lantana* cover (Fig. 18). For every 20% increase in *Lantana* cover, one native herb species was removed from plantation. The variation of shrub species due to *Lantana* invasion in WS II was less significant in plantation and not significant in vayal (Table 20). Gooden *et al.* (2009a) found that, due to *Lantana* invasion there was only little variation in the species richness of shrubs. It was noticed during their study that, some shrub species like *Pittosporum revolutum* and *Clerodendrum tomentosum* were favored by the *Lantana* invasion up to certain limit. In the current study, the shrub species *G. pentaphylla, H. isora* and *C. fistula* were seen in almost all *Lantana* invaded regions. *Lantana* had replaced *Pinus roxburghii* and *Quercus leucotrichphora* forests in Kumaun hills of Uthar Pradhesh (Bhatt *et al.,* 1994). The variation of shrub species due to *Lantana* invasion in WS II is not significant in vayal. Vayals in Wayanad WLS was frequently managed. Cummings *et al.* (2007) found that, *Lantana* management will increase the native species richness, especially the growth of shrubs. The species richness in *Lantana* managed areas will be 1.2 to 2.5 times greater than invaded area.

The herbs and shrubs varied linearly in accordance with *Senna* cover. On plotting herb species richness against *Senna* percentage cover, only four herb species were obtained from 50% of *Senna* were affected area. On further increase in percentage cover of *Senna* the herb species richness declined linearly and it was decreased to one at 100% *Senna* cover (Fig. 18). Only two shrub species obtained from *Senna* affected area. By increasing the *Senna* cover to 100%, there shrub species could be obtained from study area. But there was one herb species (*Mimosa pudica*) located at 100% of *Senna* cover.

Hypoestus phyllostachya

Crassocephalum crepidioides

Plate 9. Other IAPS found in Wayanad Wildlife Sanctuary II

Parthenium hysterophus

Mikania micrantha

Plate 10. Other IAPS found in Wayanad Wildlife Sanctuary II

Summary

SUMMARY

The study titled "Impact of invasive alien plants (IAP) on understorey vegetation in Wayanad Wildlife Sanctuary" was carried out is 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 (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 II part of sanctuary. Higher densities of *Lantana* were seen in Kurichiat RF of Kurichiat range, Rampur and Alathur RF of Sultha bathery range and Edathara RF of Muthanga range.
2. Higher densities of *Chromolaena* were seen in Kurichiat RF of Kurichiat range, Mavinahalla and Noolpuzha RF of Muthanga range, Kallur and Alathur RF of Sulthan bathery range.
3. *S. spectabilis* was seen in Rampur RF of Kurichiat range and Mavinahalla RF of Muthanga range. Higher density was seen in the border of Sulthan bathery range and Muthanga range.
4. Density (in 1 ha) of *L. camara* was 322.35 ± 88.18 (plantation), 85.42 ± 29.55 (NF) and 423.53 ± 99.40 (vayal). Density of *C. odorata* was 4943.52 ± 1079.07 (plantation), 4996.47 ± 1484.42 (NF) and 5810.59 ± 1262.43 (vayal). Density of *S. spectabilis* was 63.5 ± 31.66 (plantation), 49.74 ± 23.93 (NF). No *Senna* invasion was observed in vayal.
5. Percentage cover of *C. odorata* was highest in vayal (14.5 ± 2.2). In plantation and NF the percentage cover was 8.1 ± 1.1 and 7.3 ± 1.5 respectively. The percentage cover of *L. camara* was highest in NF (14.2 ± 2.8). In plantation and vayal the percentage cover was 7.5 ± 2.0 and 0.95 ± 0.3 respectively. The

percentage cover of *S. spectabilis* was highest in NF (6.3± 2.4) and lowest was in plantation (2.6 ± 1.6). There was *Senna* invasion in vayal.

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 LC (*L. camara* and *C. odorata*) plots. The lowest MSR was observed in S (*S. spectabilis*) plots and CS (*C. odorata* and *S. spectabilis*). When *Senna* was 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 ($F_{2, 235} = 7.04$; $p<0.001$) and weed category areas ($F_{6, 235} = 43.61$ $p<0.001$) have significant variations. The interaction between vegetation type and weed category areas also showed significant variation ($F_{12, 235} = 3.16$ $p<0.001$).
9. About 0.38% 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 0.3% and 0.31% 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* (0.55) had the primary influence on species richness of native species followed by *S. spectabilis* (0.35) and *L. camara* (0.33). In plantation both *L. camara* (0.40) and *C. odorata* (0.41) has almost similar influence on native species richness. In vayal *C. odorata* (0.54) has highest influence on species richness followed by *L. camara* (0.18).
10. Species richness in each growth form (herb & shrub) declined significantly with increasing *Lantana*, *Chromolaena* and *Senna* cover. In the present study, trees and climbers did not show significant variation with percentage covers of *Lantana*, *Chromolaena* and *Senna*. For every 10% increase in *Chromolaena* cover two herb species was missing from each vegetation types. For every 10% increase

in *Chromolaena* cover one shrub species was removed from each vegetation types.

11. In NF there were 10 herb species at first 20% of *Lantana* cover and it was decreased to 7 at next 20% of *Lantana* cover. For every 20% increase in *Lantana* cover, one native herb species was removed from plantation. The variation of shrub species due to *Lantana* invasion in WS II was less significant in plantation and not significant in vayal.
12. The herbs and shrubs vary linearly accordance with *Senna* cover. On plotting herb species richness against *Senna* percentage cover, it was found that there was only four herb species obtained from 50% of *Senna* affected area. On further increase in percentage cover of *Senna* the herb species richness declined linearly and it was decreased to one at 100% *Senna* cover. There was only two shrub species obtained from *Senna* affected area. By the increase of *Senna* cover to 100%, there was no shrub species obtained from study area. But there was one herb species (*Mimosa pudica*) located at 100% of *Senna* cover.

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

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ABSTRACT

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ABSTRACT

The present study "Impact of invasive alien plants (IAP) on understorey vegetation in Wayanad Wildlife Sanctuary" was conducted in three vegetation types (Plantation, NF and Vayal) of WS II part of the sanctuary. The distribution characteristics of selected invasive alien species (IAPS) viz. *Lantana camara* L., *Senna spectabilis* (DC.) H.S. Irwin and R.C. Barneby and *Chromolaena odorata* (L.) R.M. King & H. Rob and the impact of these invasive alien species on the regeneration of other plant communities were studied and compared.

L. camara and *C. odorata* invaded all areas of the sanctuary except in the borders of Kurichiat and Sulthan bathery forest ranges. *Lantana* invasion was high in the Kurichiat RF (Reserve forest) and Rampur RF. *Chromolaena* invasion was found to be high in Mavinahalla and Kurichiat RF. In WS II part of the sanctuary, *S. spectabilis* was mainly distributed along the boundaries of Sulthan bathery and Muthanga ranges. In Muthanga, *Senna* invasion was extended up to "Kakkapadam" (2.5 km from Muthanga station). Among the IAPS, *Chromolaena* showed the highest density in all the three vegetation types, while the density of *Senna* was lowest in all the three vegetation types in WS II area. The density of *Chromolaena* in plantation and NF was 4943.52 ± 1079.07 and 4996.47 ± 1484.42 respectively. The density of *Lantana* in plantation and NF was 322.35 ± 88.18 and 85.42 ± 29.55 respectively. The density of *Senna* in plantation and NF was 63.5 ± 31.66 and 49.74 ± 23.93 respectively. *Senna* invasion was absent in vayal. Vayal showed highest density of *Chromolaena* (5810.59 ± 1262.43). *Chromolaena* had the highest percentage cover in both plantation and vayal. In NF, *Lantana* has (14.2 ± 2.8) the highest percentage cover. In all the three vegetation types, *Chromolaena* had the highest frequency and abundance. Among the seven weed category areas identified from the study area, highest MSR (Mean Species Richness) was seen in Control (weed free area), followed by L (*Lantana* invaded) and LC (*Lantana* and *Chromolaena* invaded)

regions. The lowest MSR was obtained in S (*Senna* invaded) and CS (*Chromolaena* and *Senna* invaded) regions. All the three IAPS negatively influenced the native species richness. But no specific declining trend in species richness was observed during regression analysis. Results of regression analysis showed that, among the three IAPS, *C. odorata* had the biggest impact on the species richness of native species. It was followed by *L. camara* and *S. spectabilis.* Species richness of each growth form (herb & shrub) declined significantly with increasing *Lantana*, *Chromolaena* and *Senna* cover. In the current study, trees and climbers did not show any significant variation with increasing percentage covers of IAPS. For every 10% increase in percentage cover of *C. odorata*, two native herb species were observed being removed from the study area. At the same time only one shrub species was removed at every 10% increase in *Chromolaena* cover. For every 10% increase in *Lantana* cover, one native herb species was removed from the study area of the sanctuary. The species richness of shrubs also declined due to *Lantana* invasion. On plotting herb species richness against *Senna* percentage cover, only four herb species were obtained at 50% *Senna* cover. On further increase in percentage cover of *Senna* the herb species richness declined linearly and it was decreased to one at 100% *Senna* cover. It was also found during the study that, in plots where *Senna* and *Chromolaena* occured together, the species richness decreased from 86 to 4. Similarly in plots where *Senna* occured with *Lantana* and *Chromolaena*, species richness declined. 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. Out of the 125 plant species identified from the sanctuary, only thirteen were observed from *Senna* invaded region. But during regression analysis it was found that, among the three IAPS *Senna* has the least impact on native species richness. This may be due to the fact that compared with *Lantana* and *Chromolaena*, the invasion of *Senna* is restricted to only a small portion of Wayanad WLS. But left uncontrolled *Senna* will soon become a major threat in Wayanad WLS in the near future.