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Impact of invasive alien species-*Prosopis juliflora* on floral diversity of Sathyamangalam tiger reserve, Tamil Nadu, India

Abstract

The Bhavanisagar Range of Sathyamangalam Tiger Reserve in the foothills of the Nilgiris is one of the most famous preferred breeding grounds for the Elephants in the Western Ghats and it is known for its landscape beauty, varied of forest ecosystems and wildlife diversity. Unfortunately, during the last decades, there has been a drastic reduction in the diversity of the natural vegetation. The available niches have been occupied by invasive exotic species especially *Prosopis juliflora*. The present study deals with the impact assessment of *Prosopis juliflora* in Bhavanisagar range of Sathyamangalam Tiger Reserve, Tamil Nadu. The parameter assessed are floral diversity and its diversity indices. For floral diversity sample plot technique was followed in three different sites *viz., Prosopis juliflora* eradicated and effectively managed area, *Prosopis juliflora* invaded area and natural forest. The study results revealed that totally 79 species of trees, shrubs, herbs and grass species were recorded out of which 38 trees belonging to 22 families, 22 shrubs covering 16 families, 19 herbs and grass species relating to 14 families was recorded. In *Prosopis juliflora* invaded area, 24 tree species belonging to 11 families, 16 shrubs species occupying 13 families and 11 herbs & grasses belonging to 8 families were documented. The highest floral species contribution was from families like Fabaceae, Solanaceae and Astracese in tree shrub and herbs respectively in the study area.

The natural forest area was more diverse in flora and fauna than *Prosopis juliflora* invaded and eradicated area. The Shannon–Weiner diversity index, among the three sites, reveals that natural forest (site-III) registered more diverse, and in the case of Simpson index of dominance, the natural forest (site-III) recorded the highest dominance. With respect to Pielou's evenness index and the Margalef index, natural forest area (site-III) has registered higher index.

Keywords: floral diversity, *Prosopis juliflora* invaded area, *Prosopis juliflora* eradicated areas

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Maheshnaik BL, Baranidharan K, Vijayabhama

Forest College and Research Institute, India

Correspondence: Baranidharan K, Forest College and Research Institute, Mettupalayam TNAU, Tamil Nadu-641 301, India, Email krisberani@yahoo.com

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Introduction

Invasive alien plants are non-native organisms and they have the potential to cause, harm to the environment, economics and human health. Invasive alien species are one of the most significant drivers of environmental transformation worldwide. An invasive plant is an alien species which establishes in natural or semi natural ecosystems, an agent of change and threatens native biological diversity. According to the World Conservation Union, invasive plants are generally considered to be the second greatest threat to biodiversity after habitat destruction.[1] Exotic plant species have been purposely and/or accidentally introduced throughout the world due to their economic, environmental or aesthetic values. Nonetheless, introduction of new species is not always a success and brings about the possibility of invasiveness of the species which in turn result in negative impacts (economic, environmental and social).[2] In the late 1970s and early 1980s, concern about deforestation, desertification and fuelwood shortages prompted a wave of projects that introduced *P. juliflora* and other hardy tree species to new environments across the world[3] that it did not take *P. juliflora* a long time to be registered as one of the first top 100 invaders. During its introduction from its natives, South America, Central America and the Caribbean, the indigenous knowledge of its management and use have rarely followed direct *P. juliflora* to remain under-utilized and unmanaged.[4] In Sathyamangalam Tiger reserve the invasive species present are, *Prosopis juliflora*, *Lantana camara* and *Opuntia dillenii*. *Prosopis juliflora* and *Lantana camara*, have severely invaded into the ecosystem in many places in the Tiger Reserve. This has reduced the native floral composition and fodder availability to herbivores during the critical dry season. Such a phenomenon has been noticed in Bhavanisagar Range. Large herbivores such as Black buck, Elephants and bird communities play a major role in dispersing the seeds of those alien invasive species. It is necessary to investigate the dynamic processes of the seed dispersal by animals and also eliminate plant weeds in a slow phase to re-establish native plant species for supporting high densities of herbivores.[5] Thus, if such a noxious weed once firmly establishes itself in this most important conservation areas like Sathyamangalam Tiger Reserve, the population of vegetation including native plants would be reduced, the animals that depend upon terrestrial forage may lack feed, suffer by toxic nature of pod consumption and cause physical injuries during shelter. The suppression of grass and other native species would result in enormous economic and ecological impacts on Biodiversity. As a result of this, our country may lose such most important conservation areas with rare, diverse and endemic species and natural heritage.

To address such broad dimensions of the problem adequate research has not been conducted so far, particularly the impact assessment of invasive *Prosopis juliflora* towards biodiversity of Sathyamangalam Tiger Reserve, changes in vegetation composition, mammalian diversity and soil conditions.

Material and methods

Study area

The study area is situated with Nilgiris in the south, Sathyamangalam in the north, Bhavanisagar in east and Segur plateau in west. Geographically, the study site lies at 11º50´ N latitude and 77º07´ E longitude to 11º56' N and 77º02' and at an altitude ranging from 352 to 412 MSL. The study was conducted at Bhavanisagar Range of Sathyamangalam Tiger Reserve, Tamil Nadu, during August 2016 to May 2017. Sathyamangalam forest division is the largest in the state of Tamil Nadu, extending over 1455.76km^2 and the Bhavanisagar range consists of 241.92km^2 of forest area. The study area accounts to 35.82km^2. The Forest types found in the study area are *viz.,* Southern Tropical dry mixed deciduous forest (5A/C3), Southern Sub-Tropical hill forest (8A/C1) and Riparian forest along the Moyar River.

Stratification of the study area

The study area was stratified as follows:

a) *Prosopis juliflora* eradicated and effectively managed area (Site-I).

b) *Prosopis juliflora* invaded area (Site-II).

c) Natural forest area (Site-III, *Prosopis juliflora* non-invaded area)

Floral diversity was assessed by sampling techniques through sample plot methods. The size and number of sample plots needed were determined using the species effort area curve.[6,7] Based on species area curve various plots size were laid in different sites, area varying from (5x5m) to (30x30m). The total number of species in the plots were enumerated and it was plotted in the curve, then the plot size selected based on the curve statistics. Sample plots (quadrant) fitted for floral survey. Where 20x20m plot was used to survey all trees, on shrubs (5x5m) for herb and grasses 1x1m were observed in three different sites of the study area. The recorded flora was identified on knowledge, guidance of experience of field staffs with herbarium and Botanical Survey of India (BSI), Coimbatore.

Quantitative analysis of floral diversity

The important quantitative analysis such as density, frequency, and abundance of tree species, shrubs and herbs species are determined as per Curtis & McIntosh.[8] In order to assess the impacts of *Prosopis juliflora* comparing quantitative characters with in the three sites of the study area, the following analysis was done.

$$\text{Density} = \frac{\text{Total number of individuals of all species in all quadrants}}{\text{Total number of quadrats studied}}$$

$$\text{Frequency (\%)} = \frac{\text{Number of quadrants in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrants}}{\text{Total number of quadrats in which the species occurred}}$$

IVI=RD (%) + RF (%) + Rd (%)

Species diversity, Species dominance, Evenness and Richness indices Shannon–Weiner index of diversity[9]

The formula for calculating the Shannon diversity index is

$$H' = -\sum_{i=1}^{S} (pi \times \ln pi)$$

Where, H'=Shannon index of diversity

pi=the proportion of important value of the ith species.

(pi=ni/N, ni is the important value index of ith species and N is the important value index of all the species)

$\log_n$=Natural logarithm on proportion of each species

Simpson index of dominance[10]

Simpson index measures the strength of dominance (because It takes into account both richness and evenness). A value of this index ranges from 0-1; 0 represents infinite diversity and 1, for no diversity.[11]

$$\lambda = \sum_{i}^{S} (pi)^2$$

Where, pi=(ni/N)

ni=The total number of individuals of each species

N=No. of individuals of all the species

Pielou's evenness index[12]

It is a measure of partition of the individuals of population among species. In an evenly distributed population, J is 1. J decrease with increasing unevenness.

J=H'/ln S

Where, J= Species evenness

$$H' = -\sum p_i log_n p_i,$$

S=No. of specie.

pi=ni/N (ni is the important value index of ith species and N is the important value index of all the species).

$\log_n$= Natural logarithm on individuals of all the species.

Margalef's index of species richness[13]

The species richness of the vascular plants calculated as per the method was given by Margalef's,[13] (Dmg)

Dmg=(S-1)/ln N

Where, S=No. of species.

N=No. of individuals.

ln=Natural logarithm of total number of individuals

Results and discussions

The floral diversity study revealed that a total of 79 plant species were distributed in site-I, site-II and site-III, of Bhavanisagar range in Sathyamangalam Tiger Reserve. The maximum number of species occurred in Fabaceae, Solanaceae and Astraceae families in tree, shrub and herbs respectively. The forest type comprises in these sites

are Southern Tropical Dry Mixed Deciduous and Riparian Forest in site-I, Southern Tropical Dry Mixed Deciduous Forest was in site-II, Southern Sub-Tropical Hill Forest was in site-III. This range has three different forest types varying with sites, and due to this the range would have received good precipitation and favouring temperature. This might be the reason for the good floral diversity of the study area.

In case of *Prosopis juliflora* eradicated and effectively managed area (Site-I) with Southern Tropical Dry Mixed Deciduous and Riparian forest registered 46 species, of which 20 tree species belonged to 11 families, 13 shrubs species occupied 10 families and 13 herbs and grasses belonged to 10 families. There was no new regeneration of species on the site which was due to *Prosopis juliflora* existence previously and which was eradicated recently in May 2014 to June 2015. The lowest floral distribution was due to the invasion of *Prosopis juliflora* during last few decades and recent eradication of *Prosopis juliflora* caused the disturbance in the canopy openings, increased resource availability and also modified the micro climate. Natural regeneration of *Prosopis juliflora* follows as equal as native species, because of increase in light availability. The findings are in line with Krishnamurthy et al.,[14] reported of long-term monitoring of plant diversity and dynamics in a tropical dry deciduous forest of Bhadra Wildlife Sanctuary, Karnataka, Enumeration of all woody plants revealed that 46 species belonging to 24 families were existing.

The total plant species recorded in *Prosopis juliflora* invaded area (Site-II) of Southern tropical dry mixed deciduous forest revealed a total of 51 species, of which 24 tree species belonged to 11 families, 16 shrubs species from 13 families and 11 herbs and grasses belonged to 8 families. When compared to site-III, site-II exhibited considerably less number of species. So the *Prosopis juliflora* invasion showed the greater depressive effect on the number, density and frequency of associated species, particularly on native vegetation. Similar findings were also stated by Abdillahi et al.[15]

Among the different sites, the natural forest area (Site-III) with Tropical Hill Forest exhibited a maximum number of plant species of 69, in which 33 trees belonged to 18 families, 19 shrubs species occupied 13 families and 17 herbs and grasses belonged to 13 families. This was due to the rainfall in the site which was 800-850mm. This might be the reason for the good floral diversity of the site. Correspondingly, Jaya Kumar et al.,[16] reported that in the Kolli hills of Eastern Ghats of Tamil Nadu, in Tropical Hill forest, 19 tree species belonging to 17 families, 15 shrubs belonging to 10 families and 14 herbs & grasses belonging to 11 families in Kolli hills of Eastern Ghats of Tamil Nadu were recorded.

Density

In *Prosopis juliflora* eradicated and effectively managed area (Site-I) with Southern dry mixed deciduous and riparian forest, *Acacia planifrons, Jasminum angustifolium,* and *Barbarea orthoceras* expressed maximum density in trees, shrubs, herbs respectively. As there was no canopy effect by *Prosopis juliflora*, this caused the high density of these species. This result was similar, with Ali[17] who has concluded that density of species outside canopy effects of *Prosopis juliflora* was maximum. And also the above three species are highly suited for the Southern dry mixed deciduous forest regions and it might be the reason for higher density in this area. Similarly, Swati[18] has also reported that *Acacia planifrons, Lantana camara* had the highest density in the Southern dry deciduous forest in Bolampatty range of Coimbatore forest division.

In *Prosopis juliflora* invaded area (Site-II) of the Southern dry mixed deciduous forest of the study area, *Chloroxylon swietenia, Jasminum angustifolium*, and *Abutilon indicum* expressed maximum density among the trees, shrubs and herbs respectively. These species were not affected by *Prosopis juliflora* canopy. This three species were highly suited and has widely spread all over the area because of the favourable climatic condition prevailing there and this might be the reason for higher density in this area. The density of *Prosopis juliflora* was moderately high when compared to all other sites, similarly Niguse & Amare,[19] stated that *Prosopis juliflora* can suppress the growth of grasses under its canopy and the biodiversity by delaying seed germination and reducing plant growth in terms of roots, shoots, leaf area, stem diameter, and plant height. It also suppresses biodiversity by computing both resources and natural environment. The findings are in line with Sathya & Jayakumar,[20] who has reported that in the contemporary assessment of tree species in Sathyamangalam Tiger Reserve, Southern India, supported that *Acacia planifrons, Chloroxylon swietenia* and *Anogeissus latifolia* were the dominant species present in this area.

In natural forest area (Site-III) with Southern sub-tropical hill forest in the study area, *Albizia amara, Jasminum angustifolium,* and *Lantana camara* expressed maximum density among trees, shrubs and herbs respectively. Sundaravel[21] also reported maximum density of *Albizia amara* species in Southern sub-tropical hill forest of Hasanur range in Sathyamangalam Tiger reserve.

Frequency (per cent)

In *Prosopis juliflora* eradicated and effectively managed area (Site-I) with Southern dry mixed deciduous and riparian forest in the study area, *Albizia amara, Gmelina asiatica* and *Aerva lanata* expressed maximum frequency among trees, shrubs and herbs respectively. This might be due to the wider spread of these species in the area.

In *Prosopis juliflora* invaded area (Site-II) with the Southern dry mixed deciduous forest of the study area, *Chloroxylon swietenia, Jasminum angustifolium* and *Abutilon indicum* expressed maximum frequency among trees, shrubs and herbs respectively. Parallel research on the impact of *Prosopis juliflora* showed the great depressive effect on density and frequency of the associated species, particularly on native vegetation by Abdillahi et al.,[15] In natural forest area (Site-III) of Southern sub-tropical hill forest in the study area, *Albizia amara*, *Jasminum angustifolium,* and *Emilia sonchifolia* expressed maximum frequency among trees, shrubs and herbs respectively. Similarly, Swati[18] also reported that *Albizia amara* was the most abundant species in Southern Tropical Hill Forest in Bolampatty range of Coimbatore forest division.

Abundance

In *Prosopis juliflora* eradicated and effectively managed area (Site-I) of Southern dry mixed deciduous forest and riparian forest, the most abundant tree species was *Cassia siamea* and *Tamarindus indica, Solanum nigrum* among shrub and *Galinsoga parviflora* among herb and grass species. These species are highly suited for this forest type and this might be the reason for the abundance of these species in this area. Similarly, Sundaravel[21] stated that *Solanum nigrum* stands the highest abundance in the dry deciduous forest of Sathyamangalam Tiger Reserve.

Albizia lebbeck was found to be the abundant tree species in the Southern dry mixed deciduous forest of *Prosopis juliflora* invaded area (Site-II), *Lantana camara* and *Eupatorium adhenophorum* observed with highest value in abundance among shrubs and herb category respectively. Similar studies on the impact of *Prosopis juliflora* showed the great depressive effect on the number, density and frequency of the associated species, particularly on native vegetation as indicated by Soni et al.[22]

The most abundant species in natural forest area (Site-III) with southern sub-tropical hill forest was *Catunaregam spinosa* among trees, *Solanum nigrum* among shrub and *Barbarea orthoceras* among herb and grass species. These species are highly suited for this Southern dry mixed deciduous forest and hence are abundant in this site. Similarly, Swati[18] also reported that *Barbarea orthoceras* was the most abundant species in southern sub-tropical hill forest in Bolampatty range of Coimbatore forest division.

Relative density (per cent) for shrubs and herbs

The highest relative density among shrub species in the Southern dry mixed deciduous forest and riparian forest (site-I) was, *Jasminum angustifolium* and among herb and grass species was *Barbarea orthoceras.*

In southern dry mixed deciduous forest of site-II, *Jasminum angustifolium* and *Abutilon indicum* exhibited highest relative density among shrubs and herbs. In contrary, Dobhal et al.,[23] reported decreasing relative density of floral species, in *Lantana Camara* invaded the area in Nayar region of Uttarakhand.

In Southern sub-tropical hill forest of site-III, *Jasminum angustifolium* and *Acalypha indica* exhibited highest relative density among shrubs and herbs. Swati[18] reported that *Lantana camara* and *Centella asiatica* was maximum relative density among shrub and herb respectively at Bolampatty range of Coimbatore forest division.

Relative frequency (per cent) for shrubs and herbs

In *Prosopis juliflora* eradicated and effectively managed area (Site-I) with the southern dry mixed deciduous forest and riparian forest, *Gmelina asiatica* and *Aerva lanata* exhibited highest relative frequency among shrub and herb species respectively.

In Southern dry mixed deciduous forest of site-II, *Jasminum angustifolium* and *Abutilon indicum* exhibited highest relative frequency among shrubs and herbs. Vinay,[24] reported that *Lantana camara* and *Jasminum angustifolium* among shrub has recorded as the highest relative frequency species during his studies in assessment of tiger corridor between Mudumalai Tiger reserve and Mukurthi National Park in Nilgiri Biosphere.

In Southern sub-tropical hill forest of site-III, *Jasminum angustifolium* and *Acalypha indica* exhibited highest relative frequency among shrubs and herbs. Sundaravel,[21] also reported *Atalantia monophylla* and *Jasminum angustifolium* among shrub and *Cymbopogon flexuosus* and *Acalypha indica* among herb species respectively as the highest recorded relative frequency in Southern sub-tropical hill forest of Hasanur range in Sathyamangalam Tiger reserve.

Important value index (IVI)

Acacia planifrons, Chloroxylon swietenia and *Albizia amara* tree species found to be dominant in all three different sites, hence it indicated that the forest types in all sites are similar in their structural characters. Besides *Randia dumetorum, Sapindus emarginatus, Catunaregam spinosa, Diospyros melanoxylon, Gyrocarpus americanus, Azadirachta indica* and *Diospyros montana* tree species are dominant in site-I. (Figure 1) In case of site-II, the dominant tree species are *Catunaregam spinosa, Prosopis juliflora, Randia dumetorum, Azadirachta indica, Diospyros montana, Diospyros melanoxylon* and *Limonia acidissima* (Figure 2). Regarding site-III, *Albizzia odoratissima, Sapindus emarginatus, Albizia lebbeck, Hardwickia binate, Randia dumetorum, Diospyros melanoxylon* and *Diospyros montana* are the dominant tree species recorded (Figure 3). The findings are also in line with Sathya & Jayakumar,[20] that in Contemporary assessment of tree species in Sathyamangalam Tiger reserve, Southern India, it supported that *Acacia planifrons* has recorded highest IVI. Correspondingly, Soni et al.,[22] stated higher invasion of *Lantana camara* showed decreasing trend in IVI value and density of following species *viz., Terminalia bellirica, Butea monosperma, Barleria prionitis, Ailanthus excelsa* and *Phyllanthus emblica* while in lower invaded sites of *Lantana camara* the value of IVI, density and frequency represented an increasing trend.

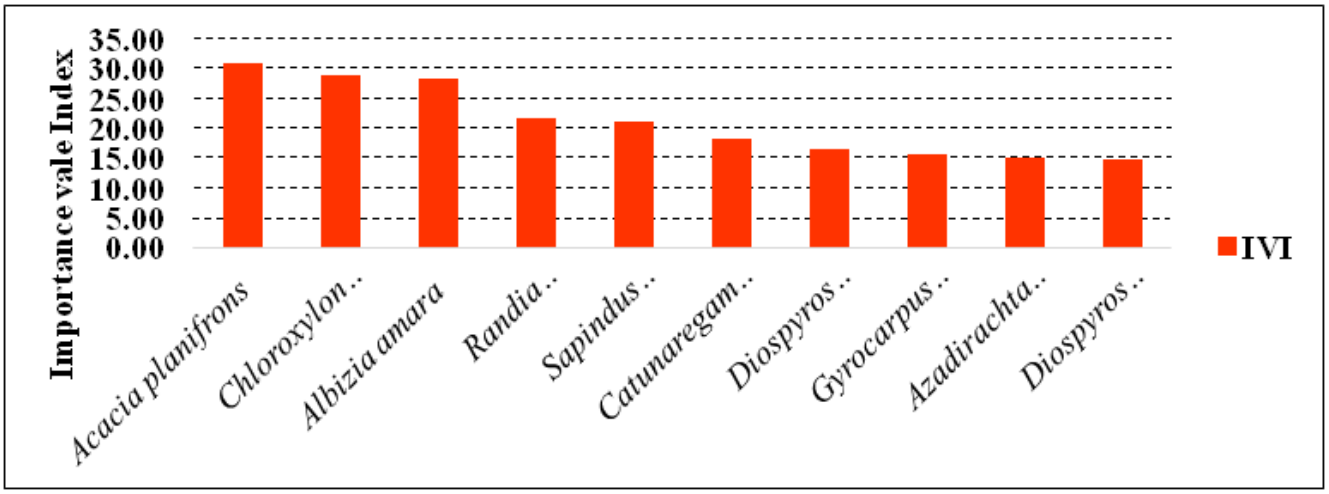

Figure 1 Importance value index (IVI) of ten dominant trees in *Prosopis juliflora* eradicated and effectively managed area (Site-I).

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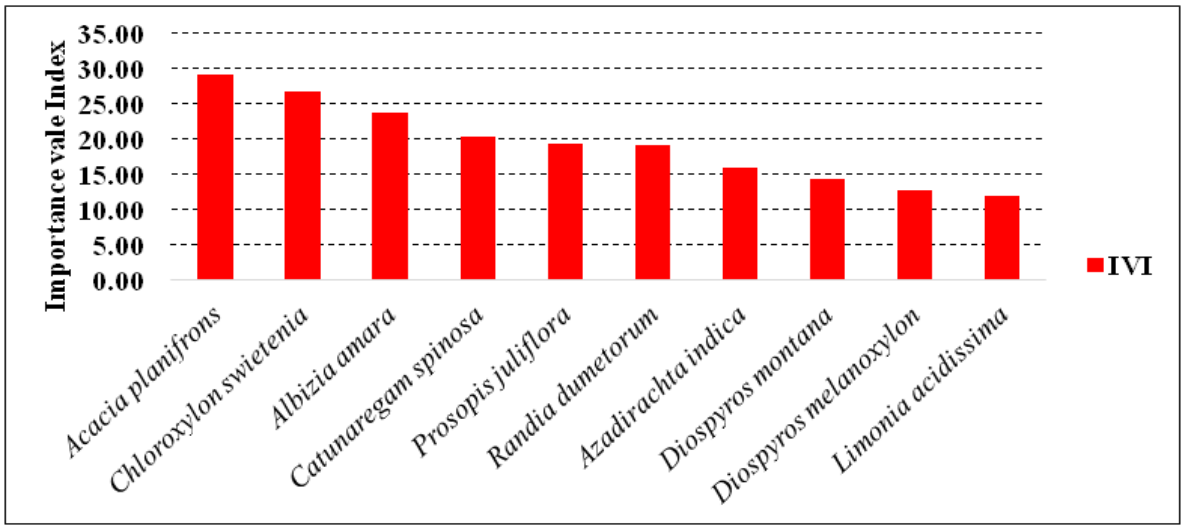

Figure 2 Importance value index (IVI) of ten dominant trees in *Prosopis juliflora* invaded area (Site-II).

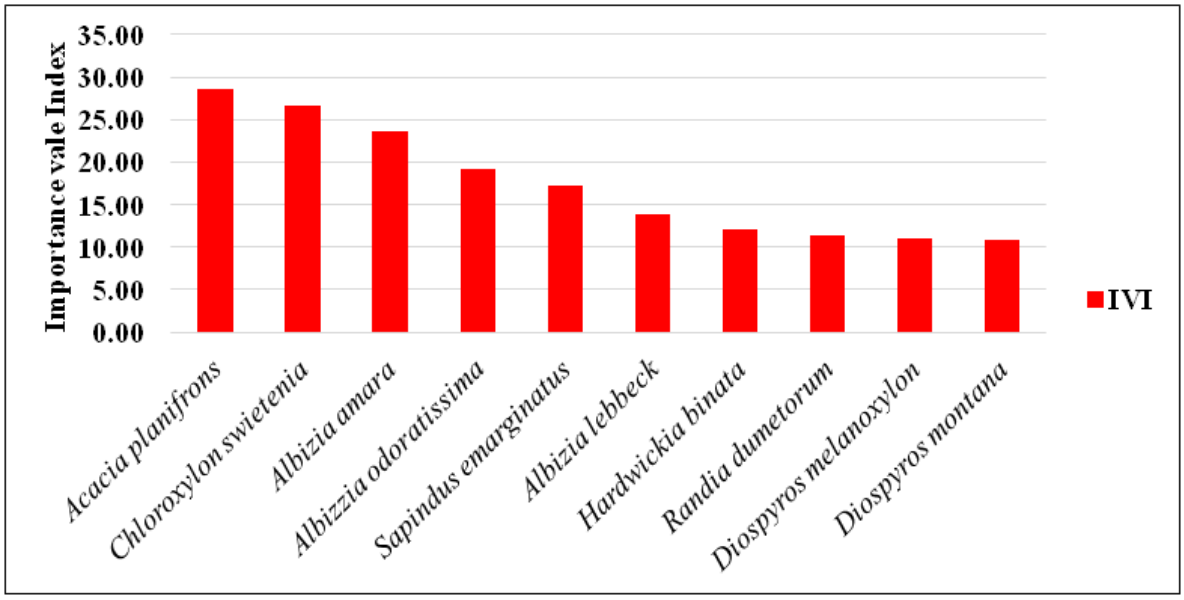

Figure 3 Importance value index (IVI) of ten dominant trees in natural forest area (Site-III).

Shannon–Weiner diversity index

With respect to Shannon Weiner index, the highest species diversity values were 3.02, 2.55 and 2.52 expressed by site-III, site-I and site-II respectively. The diversity of site-III was due to absence of the anthropogenic pressure factors towards vegetation. In regard to site-II, *Prosopis juliflora* reduced the diversity, and in site-I the area treated was under eradication of *Prosopis juliflora* so it would have caused erosion of species. Similarly, Demissie[25] reported a value of 2.31 Shannon Weiner index for the site invaded with *Prosopis juliflora* and a diversity index of 2.28 for non-invaded *Prosopis juliflora* site of Awash National Park, Ethiopia.

Simpson index for dominance

With respect to Simpson index for dominance, values 0.044, 0.055 and 0.072 was exhibited by site-III, site-I, and site-II respectively. In site-III high dominance was due to indigenous floral diversity. In site-I followed by site-II high dominance was due to the absence of *Prosopis juliflora*. In site-II, the *Prosopis juliflora* affected the floral dominance of species. Correspondingly, Demissie,[25] reported a value of 0.05 in Simpson index for the site invaded with *Prosopis juliflora* and Simpson index of 0.07 for non-invaded *Prosopis juliflora* site of Awash National Park, Ethiopia.

Pielou's evenness index for study area

Regarding Pielou's evenness index, 0.65, 0.40 and 0.39 was expressed by site-III, site-I and site-II respectively. Regarding site-III evenness was more because of native floral diversity in sub-tropical hill forest and absence of invasive plants. In site-I, the evenness was less because of eradication of *Prosopis juliflora* from the site, and in site-II covered by *Prosopis juliflora* has caused the destruction of evenness of floral species in the above site. Similarly, Awatif &

Abdullah,[26] reported that large and medium-sized individuals of *Prosopis juliflora* significantly reduced the number of species, species evenness and density under *Prosopis juliflora* when compared to outside their canopies.

Margalef's index for species richness

In case of Margalef's index for species richness, the values 4.18, 3.09 and 2.85 was exhibited by site-III, site-II and site-I respectively. In site-III richness was higher due to an indigenous floral community, followed by site-II covering were *Prosopis juliflora* tends to reduce the richness of the coexisted species, and in site-I the past invasion and eradication of *Prosopis juliflora* caused the destruction of indigenous species. Similarly, Kaur et al.,[27] reported that species richness was estimated to reduce by 63 per cent under *Prosopis juliflora* when compared to open lands. Dogra et al.,[28] reported from Sivalik hills of Himachal Pradesh that Margalef's index for the site of invasive species invaded area was 4.47 and in non-invaded area of natural forest was 7.16.

Conclusion

The forest in Bhavanisagar range was a recovery forest and lost habitat is slowly rejuvenating. It forms a part of the Nilgiris Biosphere Reserve and is one of the rich biodiversity areas of Western Ghats. Invasive alien species causing the serious threat to Tiger reserve, where *Prosopis juliflora, Lantana camara* and *Opuntia delinii* were invaded in plain and hilly regions of tiger reserve respectively. Besides these, they created a harmful effect on native environments that include displacement of native species, degradation or elimination of habitat welfare factors, alternation in soil properties, degradation of wildlife forage, adversely altered fire regime and posed a considerable threat to endangered species.

An effort was made to study the impact of *Prosopis juliflora* eradication and effective management for improvement of indigenous floral species which shows positive impacts towards rich faunal base and soil conditions of the Sathyamangalam Tiger reserve. Hence there was an improvement towards shrub and herbaceous layer composition in the *Prosopis juliflora* eradicated area showing positive trend than *Prosopis juliflora* invaded area. The assessed natural forest area (site-III) was higher in floral and faunal diversity than *Prosopis juliflora* invaded and eradicated sites. Since the area supports the enormous number of the herbivorous population like Black buck, spotted deer and the Cattle from villages are the main zoophily agents for *Prosopis juliflora* seeds. If this situation continues for few decades, the tiger reserve will be under great threat by invasive alien species. So in future more advanced ecological studies are needed to conclude this complex situation. There was immediate need of standard framework and strong modern controlling strategies (mechanical eradication, prescribed burning and chemical control) to tackle the *Prosopis juliflora* invasion towards biodiversity of Tiger Reserve. The Sathyamangalam Tiger Foundation has initiated the eco-development committees, with involvement community participation. Community-based *Prosopis juliflora* eradication in Tiger reserve will be the sustainable management strategies to ensure the ecological balance and livelihood enhancement of the local tribal community. This study will help to conclude that eradication of *Prosopis Juliflora* has a positive impact towards biodiversity and will serve as baseline data base pertaining to the management of invasive habitats by suitable management plans in Sathyamangalm Tiger Reserve.

Acknowledgments

None.

Conflicts of interest

The authors declare that there is no conflicts of interest regarding the publication of this article.

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