Study on Ecological & Socio-Economic Impact of Invasive Species, *Prosopis Juliflora* and *Lantana Camara*, and their removal from forest, common and fallow land of Tamil Nadu

FINAL REPORT

Project Investigators
Dr. G.S. Rawat
Dr. K. Sivakumar
Dr. Ruchi Badola
Dr. B.S. Adhikari

Research Fellow
Dr. B. Kamalakannan

Tamil Nadu Forest Department

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

November, 2018

Citation: Sivakumar, K., G.S. Rawat, Ruchi Badola, B.S. Adhikari and B. Kamalakannan, 2018. Study on Ecological & Socio-Economic Impact of Invasive Species, *Prosopis Juliflora* and *Lantana Camara*, and their removal from forest, common and fallow land of Tamil Nadu. Technical Report, Wildlife Institute of India, Dehradun

Final Report

1. **Title of the Project:** **"Study on Ecological & Socio-economic impact of invasive species, *Prosopis juliflora* and *Lantana camara*, and their removal from forest, common and fallow land of Tamil Nadu"**

2. **Name of the Investigators and Research Fellows:**

   Project Investigators Dr. G.S. Rawat, Dr. K. Sivakumar, Dr. Ruchi Badola and Dr. B.S. Adhikari

   Research Fellow Dr. B. Kamalakannan

3. **Funding Agency:** State Forest Research Institute, Government of Tamil Nadu

4. **Collaborating Agency:** Tamil Nadu Forest Department

5. **Duration of the Project:** May, 2017 to March - 2019

6. **Final Report Period:** May 2017 – November, 2018

7. **Date of Initiation:** May 2017
   & Completion of the project November, 2018

Contents

S No	TITLES	PAGE
	EXECUTIVE SUMMARY	1
1.	INTRODUCTION	4
2.	OBJECTIVES AND STUDY AREAS	11
3.	MATERIALS AND METHODS	26
4.	RESULTS AND DISCUSSION	28
5.	PHOTO PLATES OF STUDY STIES	51
6.	CONCLUSIONS	54
7.	REFERENCES	55

Acknowledgement:

We thank the Forest Department, State Forest Research Insititute, Government of Tamail Nadu for financially as well as logistically supported this project. We also thank all concerned forest officials including Park Managers, DFOs, DCFs, etc for helping us in the field. We thank the Chief Wildlife Warden, Tamil Nadu Forest Department for granting permission to conduct this study inside the Tiger Reserve. We thank the Director, Wildlife Institute of India for his guidance and support for this study. Further, we also thank the CAMPA-Dugong Project of MoEF&CC, Government of India, for supporing logistics to conduct field works in the sountern zone of the Tamil nadu.

Executive Summary

1) Prosopis juliflora is an invasive, drought resistant, evergreen fast growing pheratophyte widely distributed in India and also in arid and semi-arid tropical countries. It is a highly valued wood source for rural people in India. The P. juliflora is believed one of the worst invaders affecting natural and man-made ecosystems and its local biodiversity in Tamil Nadu. In this context, this study was conducted aimed to assess the distribution patterns of P. juliflora and its impacts in three different agro-climatic zones of Tamil Nadu.

2) In 1959, Prosopis juliflora was introduced in Tamil Nadu to meet the fuelwood requirements of the rural poor people and to re-vegetate the degraded lands but it spread at faster and occupied almost all agro-zones of Tamil Nadu. In India, P. juliflora was considered as one of the worst invaders in the country affecting natural ecosystems and local biodiversity. In order to eradicate this species from natural forests, preparation of a restoration plan is desirable with knowledge on ecology and impacts of P. juliflora in Tamil Nadu. Keeping this in view, Wildlife Institute of India with support of Tamil Nadu Forest Department assessed the extent and abundance of P. juliflora in forest, common and fallow land of Tamil Nadu. Initially, the study was started in the southern zone of Tamil Nadu and later in other agro-climatic zones of Tamil Nadu (i.e. Cauvery delta zone (Nagapattinam district), Southern zone (Ramanathapuram district) and Western zone (Sathiyamangalam Tiger Reserve, Erode district).

3) Totally ninety transects were laid randomly in three agro-climatic zones of Tamil Nadu. Each transect of 2 km length, it had six 15 m radius plots at equal distance of 400 m to quantify the environmental parameters such as vegetation structure and composition, cover percentage of grass, native herbs, weeds, animal pellet and bird abundance, etc., was recorded by using standard methods on the same transect. Influence and impact of Prosopis juliflora and its and socio-economic status were assessed by using a questionnaire survey in entire taluks of three agro-climatic zones.

4) The results revealed that occupancy of Prosopis juliflora was more in the southern zone compared to the other two zones. Southern zone occupies 79.4% of Prosopis juliflora invaded in this region than western zone (46%), and in Cauvery delta zone (32%). Density ($F = 34.35$, $P < 0.05$) and frequency occurrence (%) of P. juliflora were also higher in the southern zone followed by western zone and Cauvery delta zone. The richness and native biodiversity of plants and related herbs, shrubs were highly ruined in southern zone followed by Cauvery delta and western zone. The highest extent of Prosopis was observed in the entire seven taluks of the Ramanathapuram district (southern zone) compare to the Nagapattinam taluks (Cauvery delta zone) and Sathyamangalam Tiger Reserve ranges (western zone). Except Prosopis juliflora and Lantana camara; Parthenium hysterophorus and

Chromolaena odorata caused huge smash up to the native ecosystems in some ranges of Sathyamangalam Tiger Reserves.

5) In Ramanathapuram district, the abundances of herbs such as Tephrosia purpurea, Crotons sparsiflorus, and Cleome viscosa were significantly lesser in P. juliflora invaded plots as compared to the non-invaded plots. Relative abundance of birds such as Pavo cristatus, Conturnix conturnix and Acridotheres tristis were positively correlated with P. juliflora abundance in Ramanathapuram taluks. The western zone where the habitat dominated by P. juliflora was observed with low abundances of wild ungulates.

6) Driest environment settings of southern zone favored more P. juliflora than other two agro-climatic zones that are comparatively wet.

7) The study found that the impact of Prosopis in the forested landscapes of Tamil Nadu, especially in Sathyamangalam Tiger Reserve seemed to be adversely affecting the distribution of native biodiversity.

8) Dry zone of Tamil Nadu i.e. at Ramanathapuram the groundwater level-soil moisture conditions, humidity and temperature under the canopy cover were better in the habitats dominated by P. juliflora but in the forested landscapes such as in the Sathyamangalam TR, these environmental factors were comparatively lesser than other habitats of the zone. It reveals that P. juliflora in the forested landscape is not good for natural environmental settings as well as the biodiversity of the region.

9) In all zones that were studied in Tamil Nadu, the P. juliflora was observed to be allelopathic that discouraging other plants from growing around them and seems to be toxic to other biotas in ways that allow the invasives to monopolize the space, sunlight, and nutrients at the exclusion of other species. Plant diversity was observed significantly low at P. juliflora dominated habitats than other habitats of Tamil Nadu including in the Ramanathapuram District. In the native habitats of P. juliflora, the other species have developed a mechanism to counter the allelopathy of P. juliflora, but such defense seems to be not available to several native plants of Tamil Nadu.

10) The study could not find any significant impact of Prosopis juliflora and Lantana camara on the productivity of agricultural crops grown adjacent to the dense growth of Prosopis juliflora and Lantana camara on the bund or as a pure stand.

11) Prosopis juliflora, which is adapted to survive and thrive in diverse environments including very harsh dry environments, was a major boon for impoverished people subsisting in the Ramanathapuram District as it provides

them with badly needed valuable provisional services; fuelwood, charcoal, animal feed, constructional materials, reclamation of degraded soil, etc, but the Prosopis juliflora was observed to be adversely affecting both environments as well as native biodiversity in other zones of Tamil Nadu.

12) It was found that wetlands in the arid region are highly susceptible to Prosopis invasion and these wetlands were once used by migratory birds in large numbers but not nowadays that is might be due to high abundances of invasive species.

13) Although, alien invasive species such as P. juliflora and L. camara are adversely affecting the native biodiversity especially in the Western Zone and Cauvery Delta but it has livelihood values in the Southern Zone especially Ramanathpuram and adjoining districts of Tamil Nadu.

14) The study also found that the available nitrogen, phosphorus and organic carbon in the soil were high in highly invaded areas compared to less or non-invaded sites especially in the Southern Zone.

15) Economic analyses also revealed that the benefits of the P. juliflora invasion in the southern zone are higher than the costs. However, some aspects such as increased risk of water table and long-term ecological changes were not examined, thus making the total economic valuation incomplete.

16) P. juliflora and L. camara spread can be halted by actions such as clear cutting/up-rooting followed by burning of the stump of P. juliflora and keeping up-side down of stump of L. camara. Alternatively, ways can be found to utilize the existing stands of P. juliflora so that frequent harvesting can exert a check on its expansion in the non-forested landscape. Minimum, 10 years of weed management plan should be made mandatory of all Management Plans of all Protected Areas and other reserve forests of Tamil Nadu to successfully halt the expansion of these invasive species so that the native biodiversity are conserved.

12) The study concludes that complete eradicaton of P. juliflora and L. camara is inevitable in the forested landscapes and Proteccted Areas of Tamil Nadu. However, the study recommend that sustainable management and control of P. juliflora *may be a better solution than eradication in the Southern Zone.*

.

1. INTRODUCTION

Invasive alien plants dominate the native ecosystems and are threat to ecosystem services (Levine *et al.* 2003). It simultaneously provides the benefits and may cause negative impacts to the native ecosystems (Sala *et al.* 2006; McNeely *et al.* 2011). It have influence on natural resources of several ecosystems with high economic and other ecological values, and they alter the structure and function of ecosystems (Le Maitre *et al.* 2000; Richardson and van Wilgen, 2004; van Wilgen *et al.* 2008 and Milton *et al.* 2003). But there were no many other reports on the influence of invasive species on native biodiversity. This is because the impact of invasive species on native species is a complex event. It depends on the nature and origin of the invasive species, the environment or the habitat to which it is incorporated, its relationship with native species and other factors like global warming (McGinley, 2007). However, from the available reports it is inferred as the invasion of non-indigenous species becomes one of the major threats to biodiversity (Wilcove *et al*. 1998 and Mack *et al*. 2000). The invasive species have influence on community composition, abundance and species cover of native vegetation through complex interactions and combination of effects. They affect herbaceous vegetation through shading effect, exerting competition for utilizing available resources and moisture, hindering their growth by producing allele-chemicals.

Deforestation, desertification and fuel wood shortages in the late 1970's and early 1980's encouraged a wave of projects that introduced *Prosopis* and other hardy tree species across the world (Masakha and Wegulo, 2015). The species of *Prosopis* is found as an invasive weed in Ethiopia, Kenya, Sudan, Eritrea, Iraq, Pakistan, India, Australia, South Africa, the Caribbean islands, the Atlantic islands, Bolivia, Brazil, the Dominican Republic, El Salvador, Nicaragua, the United States and Uruguay (Iqbal and Shafiq, 1997; Pasiecznik *et al.* 2001; Bokrezion, 2008). Intercontinental introduction of *Prosopis* species have occurred over the several centuries. The first report were appeared for the introduction of *Prosopis* species from Americas to Senegal in the year of 1822, and to Australia, Hawaii, India, Philippines, South Africa, Sri Lanka and Sudan in the late 1800s and early 1900s (Pasiecznik *et al.* 2001). The genus of *Prosopis* explained by Burkart (1976), consist 44 species, it have been described and still much over confusion of genus in taxonomy (Morgan *et al.* 2017; Paesiecznik *et al.* 2001). They have been introduced globally and have been naturalized or invasive in many places (Rajmenek and Richardson, 2013). Numerous *Prosopis* genera are recognised as a major invader across the several parts of the world (Paesiecznik *et al.* 2001; Brown *et al.* 2004). The term '*Prosopis*' is listed as one of the

20 weeds of national significance in Australia and taxa in the genus are declared as major invasive species in Ethiopia, India, Kenya and South Africa, and Sudan is advocating for its eradication (FAO 2006; Australian Weeds Committee, 2012; Low, 2012; van Wilgen *et al*. 2012). After, Felker (2005), reported that there are 45 recognized *Prosopis* species found to be an invasive in world, from among them *Prosopis glandulosa*, *P. velutina*, *P. juliflora* and *P. pallida* are reported to be generally problematic.

Most of the *Prosopis* introductions were intentional, or introductions through cross border between neighbouring countries accidentally. The genus of *Prosopis* was introduced for many reasons: to provide fodder and shade in the arid areas of South Africa and Australia; for dune stabilization, afforestation and fuel wood supply in Sudan; for live fencing in Malawi; initially to rehabilitate old quarries and later for afforestation and the provision of fuel wood and fodder in Kenya; for fuel wood production and rehabilitating degraded soil in India; for local greening, ornamental cultivation and soil stabilization in many Middle Eastern countries; and for vegetation trials in Spain (Zimmermann, 1991; Ghazanfar, 1996; Pasiecznik *et al.* 2001; Choge *et al.* 2002; Chikuni *et al.* 2004; Elfadl and Luukkanen, 2006; van Klinken *et al.* 2006 and Laxen, 2007). *Prosopis* was possibly first introduced unintentionally into Botswana, Nigeria and Yemen through livestock trading with neighbouring countries (Pasiecznik *et al.* 2001; Geesing *et al.* 2004).

There are many factors that make many *Prosopis* species as successful invaders; it includes the production of large numbers of seeds that remains viable for decades, rapid growth rates, an ability to grow after damage (Felker, 1979; Shiferaw *et al.* 2004), root systems that allow *Prosopis* to efficiently utilize both surface and ground water, the depth more than 50 m (Nilsen *et al.* 1983; Dzikiti *et al.* 2013), and allelopathic and alleleo chemical effects on other plant species (Elfadi and Luukkanen, 2006). Several species of *Prosopis* can withstand the climatic extremes such as very high temperatures and low rain fall conditions, and they are not limited by alkaline, saline or unfertile soils (Pasiecznik *et al.* 2001; Shiferaw *et al.* 2004). *Prosopis* invasions can generate the social, ecological and economic benefits as well as harmful (Chikuni *et al.* 2004; Geesing *et al.* 2004; Wise *et al.* 2012). This leads to controversial issues surrounding the genus (Richardson, 1998; van Wilgen and Richardson, 2014). Some supporters promote it as a wonder plant, while others call for its eradication or contrast its positive or negative aspects, ex. Boon or Bane? (Tiwari, 1999), Pest or providence, weed or wonder tree? (Pasiecznik, 1999) Invasive weed or valuable forest resource? (Pasiecznik, 2002). Contrasting in this views, contradictory perceptions and is an unclear.

In India, *Prosopis juliflora* (Sw.) DC is one among the woody plants introduced for fuel wood, fodder, shade, livestock hedges, stabilizing sand dunes and soil reclamation (Sawal *et al.* 2014). *Prosopis juliflora* is considered one of the poor man's fuel wood, because of its fast growing nature, fuel wood capable of growing in wide range of soils (Basavaraja *et al.* 2007). It is *Phreatophyte* (A *Phreatophyte* is a deep-rooted plant that obtains a significant portion of the water that it needs from the *Phreatic* zone), evergreen fast growing, drought resistant widely distributed not only in India, but also in other arid and semi arid tropical countries and sub-tropical regions of the world (Fig. 1). *Prosopis* is a thorny, deciduous, large crowned and deep rooted bush or tree which grows up to 10 m height or more, depending on the variety and climatic conditions. *P. juliflora* has survived where other tree species have failed and in many cases become a major nuisance. *P. juliflora* continues to invade millions of hectares of rangeland in South Africa, East Africa, Australia and coastal Asia (Pasiecznik *et. al*. 2001). In 2004 it was rated one of the world's top 100 least wanted species (IUCN, 2004).

There are several studies revels that the loss if biodiversity due to *Prosopis juliflora* invasion, in all parts of the world (Cloves *et al.* 2014; Schactschneider and February, 2013; Samuel *et al.* 2012). In invaded region *P. juliflora* suppress the growth of grasses under its canopy and the cause for the loss of biodiversity (Niguse and Amare, 2016). In India species richness was estimated to reduce by 63% under *P. juliflora* invaded canopy compared to the open lands (Kaur *et al.* 2012). Kahi and Ngugi (2009), also reported that herbaceous plant species was less than 27% compared to the open areas, it also pointed out by Samuel (2009), an increase the level of *Prosopis* invasion caused to rapid decline population and diversity of native species in the invaded ecosystems. Similarly, invasion reduced the total biodiversity of the arid and semi arid regions, by reducing their abundance, distribution and ecosystem functioning in rangeland of *Prosopis* (Berhanu and Tesfaye, 2006).

Prosopis invasion have several negative impact on social, ecological and economic (Shackleton *et al*. 2014). It alters the ecosystem services includes water supply, hydrological functioning, herbivores gazing potential and soil quality (DeLoach, 1984; Bedunah and Sosebee, 1986; Archer, 1989; Le Maitre *et al*. 2000; van Klinken *et al*. 2006; Ndhlovu *et al*. 2011; Nie *et al*. 2012; Dzikiti *et al*. 2013). In Africa *Prosopis* invasion are leading causes of unfavourable impacts on local community structure and functioning and increases their vulnerability. It includes potential loss of land rights for local live stock herders, and conflict over limited natural communities (Centre for Sustainable Development Initiatives, 2009; Djoudi *et al*. 2011; Stark *et al.* 2011). In USA invasive weedy *Prosopis* genera are estimated to

cause a loss of US$200–500 million per annum to the livestock industry (DeLoach, 1984). And South Africa, costs of managing *Prosopis* invasions are substantial, averaging $35.5 million per annum (van Wilgen *et al*. 2012).

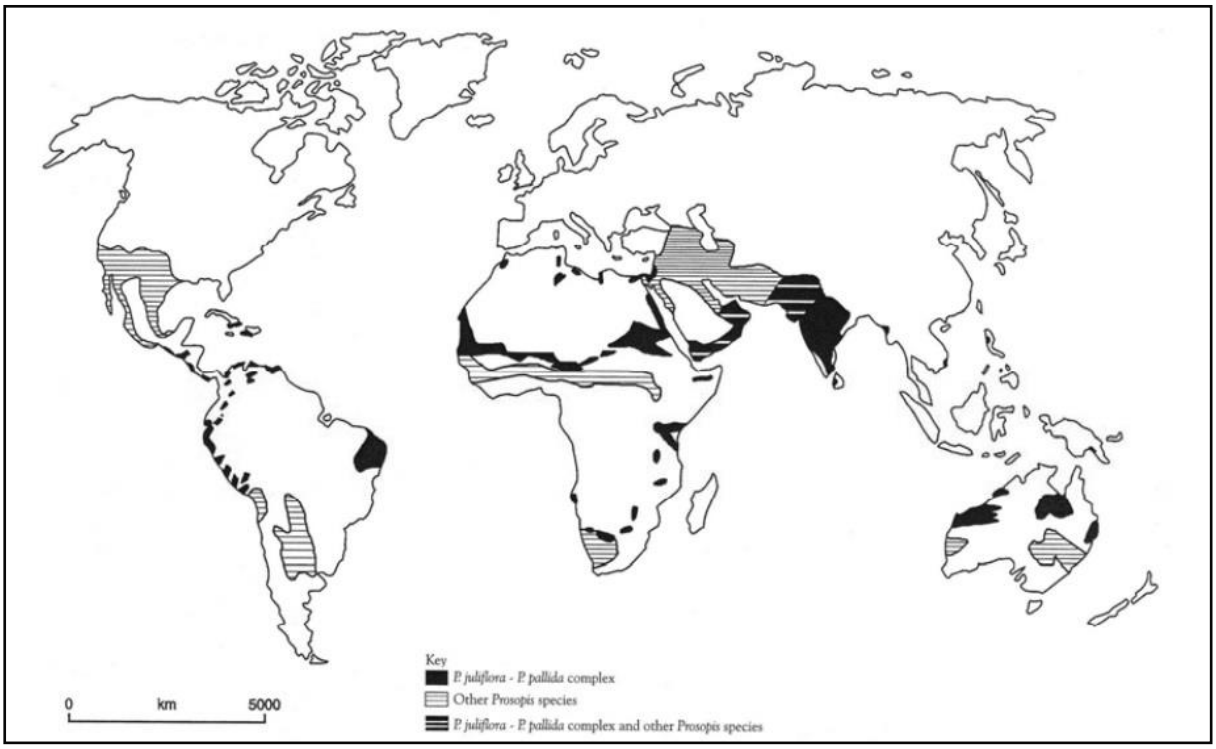


Fig. 1 Distribution status, diverse species of *Prosopis* in arid, semi-arid and tropical countries of earth (Source: Pasiecznik *et al.* 2001).

Currently species of *Prosopis juliflora* was occurring as invasive weed in several African and Asian countries including India. There was a big history behind the introduction of *Prosopis juliflora* in India, *Prosopis* first introduced into the Indian sub-continent to Sindh province (Pakistan) in 1877 from South America, and later on it was introduced into many dry regions of India (Muthana and Arora, 1983). Reddy, (1978) provides the most compelling account of the request for *P. juliflora* seed made by Lt. Col. R.H. Bedome (Conservator of Forests of Northern Circle, Madras Presidency) to the Secretary of the Revenue Department of Madras in 1876. And Conservator of Forest, Madras Presidency (1876), suggested that the introduction of these trees as fuel plantations in the dry districts of Cudappa (Andra Pradesh) by acquiring seeds from the British Consuls at Galveston and San Francisco. The Jamaican origin of *P. juliflora* seeds were sown in 1877 and out planted in 1878 (Reddy, 1978). This may have been the origin of *Prosopis* in India. Raizada and Chaerji (1954), state that the first introductions were of Mexican origin in 1877, with two supplies of seed received through the India office of Kew Gardens, UK

in 1878. Whichever account is preferred, *P. juliflora* was certainly widespread throughout India, Pakistan and Sri Lanka by the turn of the twentieth century.

In Tamil Nadu *Prosopis juliflora* were introduced in 1959, to overcome fuel shortage (Sakthivadivel, 2016) and it used for shade, timber, forage, food and medicine (Hunde and Thulin, 1989). As a result *P. juliflora* called as Seemai Karuvalum in Tamil. Naturally regenerated *P. juliflora* stands cause severe threats to the fertile landscape and agricultural lands and watersheds (Kathiresan, 2006), and its predominately distributed entire southern dry districts of Tamil Nadu and it gradually started invading cultivable fertile lands and irrigation tanks in early 1960's. During continuous drought period in the southern districts of Tamil Nadu, *P. juliflora* invasion became very severe and established strongly. The *P. juliflora* wood has high calorific value of 4200-4800 kcal kg^{-1} (Wright, 2010). It is described as wooden anthracite due to its slow and even burning capacity without smoke (Duke, 1983). The local people use the wood for cooking even when it is fresh. In general, from one kg biomass of *P. julifora* 2.5 m^3 gases could be generated which can provide 3000 kcal of thermal energy (Rao and Vasanthi, 1986).

Ecology of Prosopis juliflora

The ecology of *P. juliflora* was studied for more than 40 years (Chinnimani, 1992). It is a pioneer species with rapid colonizing tendency. It thrives well in regions with 50-1200 mm rainfall and temperature up to 48°C. It is adapted to grow in all types of soils including acid and alkaline soil with wide range of moisture conditions. It tolerates strongly in saline soils and seasonal water logging. It is highly drought resistant. It survives well at places 1200 m above sea level and in places where other trees fails to grow, but cannot grow in frost prone areas. More than forte four recognized species of the genus *Prosopis*, which have been identified and listed by Burkhart (1976). All *Prosopis* species are able to survive low annual rainfall and very lengthy dry periods (Pasiecznik *et al.* 2001). *Prosopis* has a lesser competition and greater security (from grazers/predators) than in its native habitats (Abbasi and Nipaney, 1986; Ganesh *et al*. 2005; Walter, 2011). *P. juliflora* pods have nutrient poor embryos with nutrient rich seed coats. It was suggested that leaching of nutrients from the seed coat aids seedling establishment by assisting rapid growth of the embryo following germination and the creation of a favourable micro environmental conditions (El-Sharkawi *et al.* 1997).

It has following important characters:

1. They are very hardy, tolerating wide range of temperature, water, soil and atmospheric humidity
2. They grow vegetatively and/or through seeds, and it produces huge numbers of seeds with efficient dispersal mechanisms, high germination success in invaded regions.
3. They have fast growing ability, dormant of seeds and attractive taste of pods for many live stocks, seed maintaining viability in the live stock and wild animals droppings, it resistance to browsing and high ability of re-growth (Shiferaw *et al.* 2004).
4. They are highly allelopathic in nature, and it produces certain alleleo chemicals to discourage the nearby plants, which grows around them.
5. It used high water efficiency (Felker *et al.* 1983), contribute to its invasion. Based on this character and ecology, *Prosopis juliflora* has become the invasive species in India.

Nutrient dynamics and allelopathic effects of Prosopis juliflora

Nutrient dynamic studies are essential to understand the ecological status and functioning of an invade ecosystems of *Prosopis juliflora*. Nutrient cycling or turnover is mainly regulated by arboreal vegetation in an ecosystem. Invasive tree species bring series of changes in ecological and soil physico-chemical characters in invaded region. The nature of changes brought by them depends on their type, rooting pattern and quantity of litter fall. The studies conducted by Nair (1987) in different parts of the world showed that the effect of trees on soil properties varies from region to region and the magnitudes of beneficial and adverse effects mediated by them depend on site specific features.

The earlier studies on plant soil interactions suggest that an exotic invasive species has the capacity to change many components of bio-geochemical cycles in an ecosystem. The effect of woody invasive species is different from herbaceous invasive species (Simmons *et al.* 2007). However the introduction of new species alters nutrient dynamics by altering physical properties of soil (Boettcher and Kalisz, 1989; Finzi *et al*. 1998; Kelly *et al*. 1998). Soil physical and chemical properties changed during the course of sequence and the effects of plants on these changes dominate particularly during the primary succession. *Prosopis* positively affect soil physic-chemical properties in various ecosystems ranging from deserts, shrub lands to agro-forestry systems (Schade and Hobbie, 2005; Wick and Tiessen, 2008; Yadav *et al*. 2008; Perroni-Ventura *et al*. 2010). In addition, other factors such as climatic conditions (precipitation and air temperature), land management practices, soil texture, age of the trees and agro-forestry composition, might affect soil physicochemical properties as well. Therefore, research findings

cannot be generalized for all sites with different plant diversities, soil managements and climates (Schade and Hobbie, 2005; Kahi *et al*. 2009; Reis *et al*. 2009).

Prosopis invaded ecosystem had greater C and N stocks than native ecosystem (Vitousek and Walker, 1989; Hibbard *et al*. 2001). The reports of Ehrenfeld *et al.* (2001) stated that soils in the sites with invasive plants have higher rates of nitrogen mineralization and nitrification which suggests that plant invasion have positive feedback to further invasion. However, other reports on plant invasion stated that plant invasion has negative effects on C and N cycles. C loss was observed in grassland ecosystem invaded by woody plants (Jackson *et al.* 2002). The soil N stock decreased with an invasion of grass into dry tropical forests (Johnson and Wedin, 1997). The invasive *P. juliflora* is not an exemption. There are reports states that *P. juliflora* had soil ameliorating property. It improves soil fertility through efficient cycling of nutrients (Aggarwal, 1998; Singh, 1998). On the other hand there are other reports revealed that *P. juliflora* causes substratum degradation and cause loss of potassium in waterlogged environment and increase sodium, potassium and salt concentrations of soils in dry conditions (Sharma, 1993). *P. juliflora* effectively make better than that of soil affected by salt to increasing the available N, P, and K in Central dry zone of Karnataka with sodic soil (Basavaraja *et al*. 2007). In saline soils, the roots of *P. juliflora* absorb salts from the soil and retained them in stem. On decomposition, the litter releases nutrients and aid in soil reclamation (Kanzaria and Varshney, 1998). Similarly large amount of nutrient release was recorded in coastal ecosystem. Ahmed (1991), reported that *P. juliflora* returns more to the soil after ten years of growth through litter decomposition and help in soil fertility restoration. Hence it has both positive and negative influence on nutrient cycling the study was to understand site and influence of *P .juliflora* in nutrient cycling and soil properties.

Prosopis juliflora is the only exotic species capable pH growing on a wide variety of soils and climatic conditions. It is able to grow satisfactorily without alterations up to pH 9 in soil. It known to inhibit the germination of seeds/ seedlings of other species of plants the lie in its nearby (Muturi *et al.* 2017; Shaik and Mehar, 2015). *Prosopis* recognised as an invasive, and its harmful effects on different plant species in their invaded region, due to the presence of allelochemicals. Allelochemicals or allelopathic compounds are metabolites, which it is released from plants and it can be beneficial detrimental to the growth of receptor plants (Chang-Hung, 1999). *P. juliflora* releases allelochemicals from its leaves, bark, and root as well as pods.

2. OBJECTIVES

The study was conducted in three agro-climatic zone of Tamil Nadu. The ecological and socio-economic conditions of the three zones vary from one to each other. Thus, ecosystem dependent variations of the invasion, invasiveness, and impact of *P. juliflora* are expected. The following objectives were outlined based on this presumption.

- Assess the status and distribution patterns of *Prosopis juliflora* presents in three agro-climatic zones of Tamil Nadu by using quatrat and circular plots.
- Ecology of *P. juliflora* and its impacts on forest, common land in three agro-climatic zones of Tamil Nadu, including inventories of native biodiversity i.e. herbs, shrubs, trees, domestic and wild ungulates in invaded region of selected study sites.
- Status and habitat use of wild ungulates in *Prosopis juliflora* dominated area measured by using line transect and pellet abundance.
- Assess the impacts of *P. juliflora* on socio-economic status of rural community by providing valuable provisional services in three agro-climatic zones of Tamil Nadu.
- To understand the allelopathic effects of *Prosopis juliflora* in invaded regions.

STUDY AREA

State of Tamil Nadu

In India, State of Tamil Nadu has 17% of its total geographical area covered by forest, out of which 15% (22, 643 Km^2) of recorded forest covered by under Protected Area with 8 Wildlife Sanctuaries, 13 Bird Sanctuaries, 5 National Parks, 4 Tiger Reserves, 4 Elephant Reserves and 3 Biosphere Reserves. These Protected areas of the state are mainly managed for conservation of biodiversity, education, recreation and preservation of historic sites, maintain unique landscapes and seascapes. Tamil Nadu is endowed with rich biodiversity, rich biodiversity of marine coastal systems in the Gulf of Mannar to terrestrial evergreen forests in the Western Ghats. Tamil Nadu shares the Western Ghats (one of the 25 biodiversity hotspots) with the states of Kerala, Karnataka, Goa, Maharashtra and Gujarat. It shares the Eastern Ghats with the States of Andhra Pradesh and Orissa.

Floral and Faunal diversity

Tamil Nadu ranks 1st among the states in the country with respect to the Angiosperm diversity with 5640 flowering plant species. It accounts for nearly one-third of the total flora of India. This includes 533 endemic species, 230 red listed species, 1559 species of medicinal plants and 260 species of wild relatives of cultivated plants. The Gymnosperm diversity of the country is 64 species, of which four species are indigenous Gymnosperms and the rest are introduced species.

In Tamil Nadu, the faunal diversity includes 165 species of fresh water Pisces, 76 species of Amphibians, 177 species of reptiles, 454 species of birds and 187 species of mammals are present. According to the CAMP reports the red listed species include 126 species of Pisces, 56 species of Amphibians, 77 species of reptiles, 32 species of birds and 40 species of mammals present in Tamil

Nadu. In this zone endemic fauna includes 36 species of Amphibians, 63 species of reptiles, 17 species of birds and 24 species of mammals are present.

The Tamil Nadu has the richest invasive species diversity. A total 1274 species were introduced in Tamil Nadu, among these 998 species under cultivation, remaining 276 species considered as naturalized or invasive (http://tnenvis.nic.in/tnenvis_old/IASintamilnadu.htm). In Tamil nadu several naturalized or invasive plants are used by the people for medical purposes (ex.) *Phyllanthus amarus*, *Aloe vera*, *Senna occidentalis* etc. Totally 79% of alien flora of Tamil Nadu exists only for cultivation, more than 200 alien species occurred as naturalized weeds, and 56 species are found both in cultivation as well as naturalized. It came from tropical America origin, used in medicinal and Ayurvedic purposes (Narasimhan *et al*. 2010). These weeds growing in different landscapes grow luxuriant in forest and cultivated areas of Tamil Nadu.

Agro-climatic zones

Prosopis juliflora is an alien invasive plants spreading throughout the Tamil Nadu, and as well elsewhere in many district of entire Tamil Nadu. Invasiveness of *P. juliflora* is known to exert significant impact on the natural vegetation communities as they cause their displacement and hence exert imbalance in the natural and agricultural ecosystem. This difference causes the formation of large monoculture of invasive plants in the alien environment. The *P. juliflora* affects not only the species diversity of the native areas, but also their ecological integrity. They grows faster, it have a greater reproductive potential, competitive ability, high plasticity character and allelopathic effects, that makes them successful invaders of non native habitats. The present study deals with the impacts and distribution status of *Prosopis juliflora* were assessed by direct field survey method, and selected three agro-climatic zones I. Cauvery delta zone (Nagapattinam district), II. Southern zone (Ramanathapuram district), III. Western zone (Sathyamangalam Tiger Reserve, Sathyamangalam Forest Division, Erode district) of Tamil Nadu (Fig. 2).

Based on characteristics of soil, rainfall distribution, irrigation patterns, cropping patterns and other ecological and social characteristics, the state of Tamil Nadu has been classified in to seven agro-climatic zones (Source: http://tnhorticulture.tn.gov.in/horti/agro-climatic-zones) in Table 1.

Table. 1 Different agro-climatic zones of Tamil Nadu (***Bolded district names represents selected study sites of Tamil Nadu***)

S No	Agro-climatic zones	Districts covered	Soil types
1	North Eastern zone	**Kancheepuram**, Tiruvallur, Cuddalore, **Vellore**, Villupuram and Tiruvannamalai	Red sandy loam, Clay loam, Saline coastal alluvium
2	North Western zone	Dharmapuri, Krishnagiri, **Salem** and Namakkal (part)	Non calcareous red, Non calcareous brown, Calcareous black
3	Western zone	**Erode**, Coimbatore, Tiruppur, Theni, Karur (part)	Red loamy and Black soil
4	Cauvery Delta zone	Thanjavur, **Nagapattinam**, Tiruvarur, Trichy and parts of Karur, Ariyalur, Pudukkottai and Cuddalore	Red loamy and Alluvium
5	Southern zone	Madurai, Sivagangai, **Ramanathapuram**, Virudhunagar, Tirunelveli and Toothukudi	Coastal alluvium, Black, Red sandy soil and Deep red soil
6	High rainfall area	**Kanyakumari**	Saline coastal, Alluvium and Deep red soil
7	Hilly zone	The **Nilgiris** and Kodaikanal (Dindigul)	Lateritic

Three major sites viz., Cauvery delta zone (Nagapattinam district and Point Calimere WS), Southern zone (Ramanathapuram district) and Western zone (Erode district: Sathyamangalam TR) were selected for the extensive data collection.

Fig. 1 Map showing the different agro-climate zones of Tamil Nadu
(Source: tnsdma.tn.gov.in)

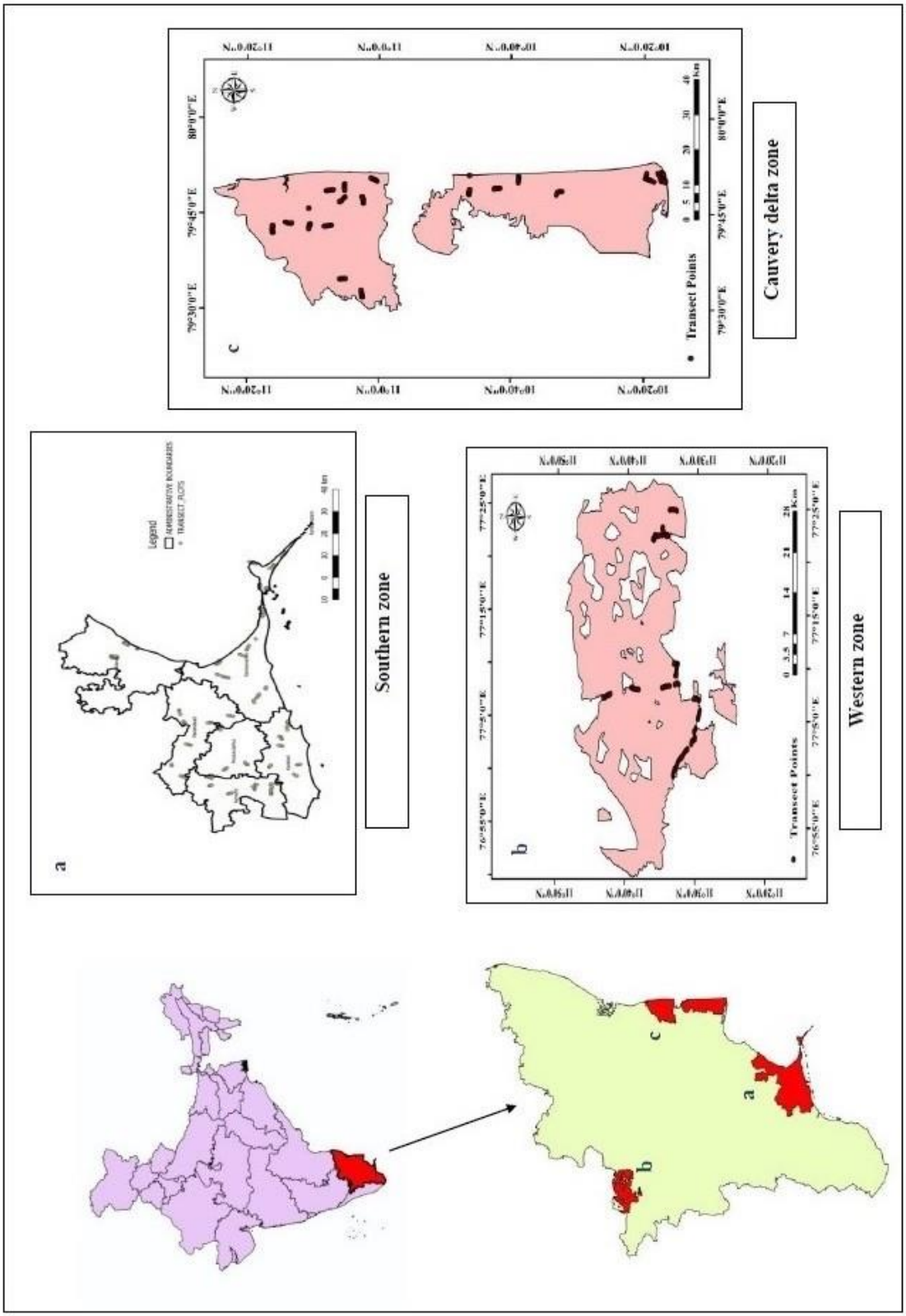


Fig. 2 Map showing study sites of three agro-climatic zones of Tamil Nadu

I. Cauvery Delta Zone: Nagapattinam District & Point Calimere Wildlife Sanctuary

Nagapattinam (10° 16' 31.21" to 11° 23' 12.08" and Longitude of 79° 49' 14.94" to 79° 49' 42.83") is one of the coastal districts of Tamil Nadu, its entire stretch about 187 km (Fig. 3). Nagapattinam district has been carved out as a separate district due to divergence of Thanjavur district. It lies on the east coast to the south of Cuddalore district and another part of the Nagapattinam lies to the south of Karaikal and Tiruvarur districts. The district forms one of seven agro-climatic zones, and part of the Cauvery-delta zone of Tamil Nadu.

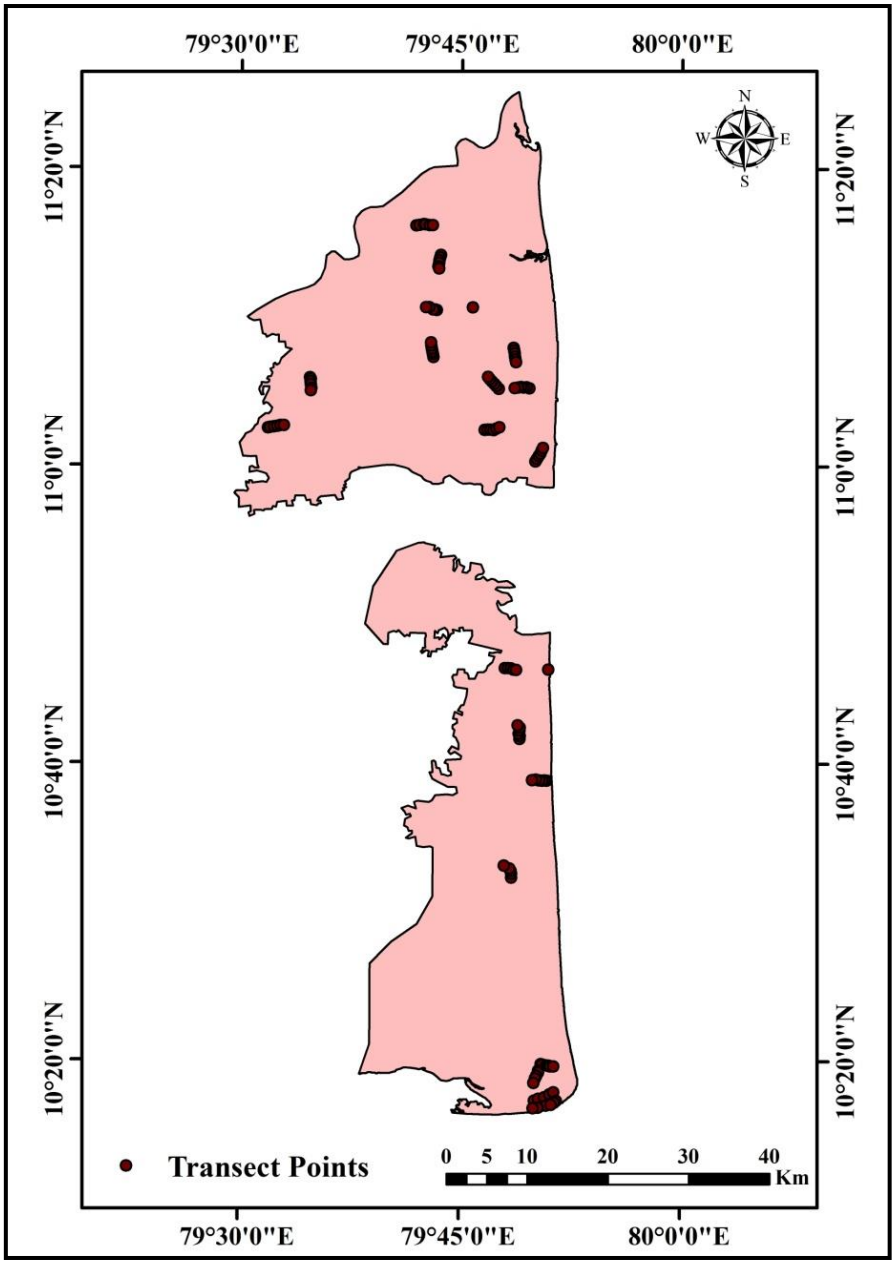


Fig. 3 Map showing study sites of Cauvery delta zone (Nagapattinam district), south east coast of Tamil Nadu.

Based on administrative purpose Nagapattinam divided 2 revenue divisions, 4 Municipalities, 11 town Panchayats unions, 8 town Panchayats and 523 revenue villages in the district. And Nagapattinam consists of eight taluks namely Sirkazhi, Nagapattinam, Mayiladuthurai, Vedaranyam, Tharangambadi, Kilavelur, Kuthalam and Thirukkuvalai. Community development blocks in the district are Keelaiyur, Kilvelur, Kollidam, Kuthalam, Mayiladuthurai, Nagapattinam, Sembanar Koil, Sirkazhi, Talanayar, Thirumarugal and Vedaranyam (http://www.kvknagapattinam.com/dtp.html). Based on census (2011), the district of Nagapattinam had a population of 1,616, 450 individuals, with a sex-ratio of 1025 females for every 1,000 males, proportion to Tamil nadu population are 2.24%. The average literacy of the district was 83.59%. As per Census 2011, 77.44% of total population of Nagapattinam district lives in rural areas of villages.

Climate and rainfall

The average maximum temperature for the Nagapattinam districts is 32.4°C and the average minimum temperature is 24.6°C. The southwest monsoon winds sets in April, strongest in June and continues till end of September. The northeast monsoon contributes 60% total annual rainfall, which it starts in October and ends in December. The average actual rainfall of Nagapattinam district is 265.2 mm and 250.6 mm respectively. During the period of southeast monsoon rainfall is 908.8 mm and it is 969.2 mm during the period of northeast monsoon. Entire district of Nagapattinam covers around 88.71% sandy coastal alluvium soil and 6.58% of black soil respectively. The other soil comprises remaining 4.71% of the district. The district is located in the deltaic region of the river Cauvery and Vennar sub basin. River Kollidam forms the northern boundary of the Nagapattinam district, where as Arasalar, Thirumalairajan, Vettar, Vennar and Uppanar, rivers drain the other part of it. Canals serve nearly 80% of the total area irrigated only by the river Cauvery, its feeds these canal. An agriculture activity contributes one of the major economic performance of the districts, it shares higher amount of rice production in the state. Other important crops of the districts include groundnut, pulses, sesamum, sugarcane and cotton etc. In Nagapattinam large areas are covered by vegetable and fruit crops that are the economic sources for rural people (http://www.tnenvis.nic.in/WriteReadData/UserFiles/file/15_NAGAPATTINAM_RAINFALL.pdf). More than 70% of total land of Nagapattinam district was occupied by cultivation and irrigation purposes, forest land and fallow land occupied by 2% and 7% only (http://dcmsme.gov.in/publications/traderep/Nagapattinam.htm#link1).

The Nagapattinam has the coastal line of 187 km including the stretch of 17 km in Karaikal (Mageswaran *et al.* 2015). Fishery is the economic back bone of the Nagapattinam district. Numerous chemical industries and aquaculture farms are also developing along this coastal zone and threaten to the many mangrove forests and marine biota in Nagapattinam district.

Forest cover of Nagapattinam

Nagapattinam district covers are about 41 forest area and it constitutes a total area of 5,311.70 ha. Based on this, 35 forest areas is under Reserve Forest category it covers 5,037.21 ha and remaining 6 under Reserve land category covers 274.49 ha, all forest activities in the district are being carried out by Wildlife division, with Wildlife Warden as administrative head. The important forest and wildlife areas in the division include Point Calimere wildlife sanctuary.

Point Calimere Wildlife Sanctuary

Point Calimere wildlife sanctuary is located in Kodiyakarai, which is facing to Srilanka and lies where the Palk Strait and Bay of Bengal meets each other. It is located 60 km from Nagapattinam, and sanctuary covers nearly 30 sq.km of Tropical dry evergreen scrub forest, which it is covered rich in floristic and more diversified plant species. The area extends around 3000 ha across the coastal habitat. The sanctuary has three unique landscapes i.e. the tropical dry evergreen forest at Point Calimere, the great Vedaranyam swamp and the Talainayar mangrove reserve forest which help tremendously support for disaster management by acting bio-shield during the time of Tsunami and floods. (http://www.tnenvis.nic.in/WriteReadData/UserFiles/file/15_NAGAPATTINAM_RAINFALL.pdf).

Floral and faunal diversity of Point Calimere Wildlife Sanctuary

According to Champion and Seth (1968), classification it had been classified into tropical dry evergreen scrub forest that is rich in floristic and more diversified plants forms and in some species of larger dimension approaching that of Sri Lankan species. *Manilkara hexandra* locally called Palai is the most important evergreen key species of the sanctuary. Besides, *Maba buxifolia*, *Memecylon edule*, *Lannea coromandelica*, *Syzygium cumini*, *Salvadora persica*, *Cassia fistula* and *Pungamia pinnata* are the most predominant species of the sanctuary. A total number 364 species of plants have been recorded in this sanctuary, including herbs, shrubs and trees. And it occupies almost 198 species of medicinal plants, like *Tinospora cordifolia, Capparis diversifolia, Solanum trilobatum, Capparis zyylonica, Toddalia asiatica, Hygonia mystex, Cissus vitonea, C. quadrangularis, Aprus procatories, Mucuna pryrita, Trichosanthes*

palmate, Tylopora ashthmatica, Mucuna pruriens, Randia dumatorum and etc. Point Calimere wildlife sanctuary is home to the largest population of the endangered species like Blackbuck and Monitor lizard species in south India. And also wildlife sanctuary supports other species spotted dear, wild boar, bonnet macaque, civet cat, feral horse, black napped hare, jungle cat, jackal including a variety of reptiles.

From the period of monsoon and post-monsoon season nearly 90 species of migratory water birds visit the sanctuary and its surroundings. Insectivorous like *Drosera indica* and *D. burmani* appeared only in monsoon period of this sanctuary. Point Calimere sanctuary includes Flamingo's, painted strokes, pelicans, spoonbills, ducks, and shore water birds. So, Point Calimere wildlife sanctuary is listed as an Important Bird Area (IBA) for India. And one of the internationally recognized sites of Olive Ridley turtle is situated in Point Calimere sanctuary. In middle of sanctuary canopy were dominated by *Prosopis juliflora* vegetation, and threat to native diversity of the sanctuary. So our study aims to assess the distribution status of *Prosopis juliflora* in Nagapattinam districts as Cauvery delta zone of the Tamil Nadu.

II. Southern Zone: Ramanathapuram District

Ramanathapuram district (9°05'- 9°50'N and 78°10'- 79°27'E) is a southern coastal district of Tamil Nadu (Fig. 4). It covers an area of 4089.57 km^2. The district is bounded on the south by Thoothukudi and Thirunelveli district, on the west by Sivagangai and Virudhunagar district, north by Pudukkottai district, on the east by Bay of Bengal and the Gulf of Mannar.

It has a long coast line measuring about 241 km^2. It consists of 7 taluks, 11 blocks and 429 Panchayat villages. Based on census (2011), the district of Ramanathapuram had a population of 1,353,445 individuals, with a sex-ratio of 983 females for every 1,000 males, much above the national average of 929. The average literacy of the district was 72.33%. The district had a total of 3, 23,905 households. There were a total of 6,02,977 workers, comprising 1,49,959 cultivators, 1,03,592 main agricultural labourers, 18,546 in household industries, 2,14,053 other workers, 1,16,827 marginal workers, 23,808 marginal cultivators, 50,282 marginal agricultural labourers, 6,682 marginal workers in household industries and 36,055 other marginal workers. The study was performed in entire seven taluks ie. Kadaladi, Kamuthi, Mudukulathur, Paramakudi, Ramanathapuram, Rameshwaram and Tiruvadanai of Ramanathapuram districts.

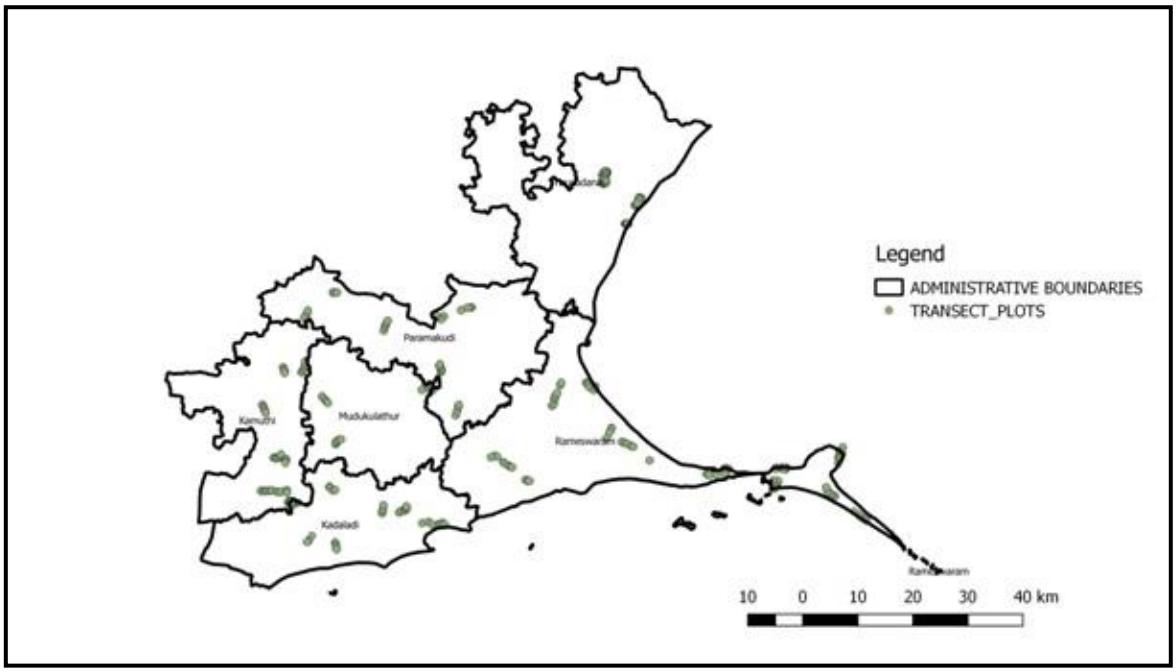


Fig. 4 Map showing Ramanathapuram district, southern zone of Tamil Nadu

The present study deals with the impacts and distribution status of *P. juliflora* were assessed by direct field survey method, and selected entire taluk as study sites in Ramanathapuram district of Tamil Nadu. *Prosopis juliflora* shows more aggressive growth in entire districts of Ramanathapuram especially in river banks, water reservoirs, roadsides and in inhabited sites. In all taluks, *P. juliflora* were naturally regenerated and appeared as weedy growth. They were distributed in scattered manner and were of open woodland type. It significantly affects the livelihood of rural population and biological diversity of entire invaded sites.

Climate

Ramanathapuram district commonly referred as a drought prone region in Tamil nadu. The district has a dry, hot weather condition throughout the year except the North East monsoon season in November and December. The climate is hot tropical with relative humidity of 80-90%. The mean annual rainfall is 827 mm. The maximum rainfall (around 502 mm) is received during North East monsoon. The average monthly minimum temperature is 22.5ºC and maximum temperature is 37.8ºC. The entire area of this district consists of laterite soil, black soil and sandy soil. The major rivers of the district are Vaigai, Gundar, Uppar, Sarugani river, Kottakarai river, Virusuli river and Pambar river. These rivers are benefited only by the North East monsoon and maximum floods occur during November, which is the peak irrigation period in the district.

Floral diversity of Ramanathapuram district

The river banks of Ramanathapuram districts are bordered by almost with natural vegetation forming fences to the cultivated lands on either side (Balasubramaniam 1991). Common trees seen along the banks are *Tamarindus indica*, *Acacia nilotica* subsp. *indica*, *A. planifrons*, *Azadirachta indica*, *Borassus flabellifer*, *Ficus benghalensis* and *Ailanthes excelsa*. Shrubs like *Opuntia stricta* var. *dillenii*, *O. monocantha*, *Euphorbia antiquorum*, *Calotropis gigantea*, *Phoenix pusilla*, *Agava cantula*, *Azima tetracantha*, *Ipomoea carnea* subsp. *fistulosa* and *Phyllanthes reticulates* are commonly found, while tall herbs like *Arundo donax* and *Saccharum spontaneum* occurs almost throughout the banks. Common herbs like *Bacopa monnieri*, *Cyperus arenarius* and *Phyla nodiflora* grow as the natural sand binders. Apart from these, the common herbs seen in Ramanathapuram are *Aerva persica*, *Datura metel*, *Gisekia pharnaceoides*, *Tephrosia purpurea*, *Borreria hispida*, *Tribulus terrestris*, *Cyperus difformis*, *Fimbristylis cymosa*, *Vahlia dichotoma*, *Ammannia baccifera*, *Croton bonpiandianus*, *Aristida setacea*, *Dactyloctenium aegyptium*, *Boerhavia diffusa*, *Ipomoea pescaprae*, *Chloris barbata*, and *Acalypha indica* and associated few grass like *Sporobolus virginicus, Paspalum vaginatum* and *Zoysia matrella.*

There is no herbaceous vegetation present in some places of Ramanathapuram district because of it cannot survive due to the high wind velocity and sand drift. The dominating trees of this region are *Cocos nucifera*, *Borassus flabellifer* and *Casuarina equisetifolia* and it is not uncommon to see stems of these tall trees which have their origin in the soils underlying these dunes partially or wholly buried in the sand. This type of forest is seen extensively all over the Ramanathapuram district both in private and government lands, the latter being restricted to isolated patches near the Sayalkudi, Mandapam, Sethukarai and Thondi regions.

Due to much biotic interference, the vegetation is of a xerophytic nature in dry lands. Some of the common trees are *Azadirachta indica*, *Tamarindus indica*, *Acacia nilotica* subsp. *indica*, *Albizia amara*, *Borassus flabellifer*, *Cordia oblique*, *Ficus benghalensis*, *Morinda pubescens* and *Delonix elata*. Shrubs like *Cadaba fruticosa*, *Calotropis gigantea*. *Abutilon indicum*, *Ipomoea carnea* subsp. *fistulosa*, *Euphorbia antiquorum*, *Capparis sepiaria*, *Senna auriculata*, *Ehretia microphylla*, and *Glycosmis mauritiana.* Some of the common climbers found among the shrubs are *Cissampelos pareira* var. *hirsuta*, *Cardiospermum halicacabum*, *Rivea hypocrateriformis*, *Coccinia grandis*, *Hemidesmus indicus*,

Pergularia daemia, *Oxystelma secamone*, *Tylophora indica* and *Tragia plukenetii* (Balasubramaniam, 1991).

III. *Western Zone: Erode (Sathyamangalam Tiger Reserve)*

The Indian sub continent is extremely diverse in the terms of climate, rain fall, vegetation and forest types. Vegetation ranged from alpine ecosystem to tropical rainforest (Ravindranath and Sukumar, 1998). The biological diversity of forest of India has resulted in four regions namely, Western Ghats, Himalayas, Indo-Burma and Sunderland, being designated as Biodiversity hotspots among 34 hotspots (Mittermeier *et al.* 2005).

The study was conducted in Sathyamangalam Tiger Reserve (Fig. 5), Sathyamangalam forest division, which is a foot hill of the Nilgiri Biosphere Reserve. Sathyamangalam tiger reserve sanctuary is a protected area in south India, declared in 2008 and enlarged in 2011, which covers forest area of 1,411.6 km^2.

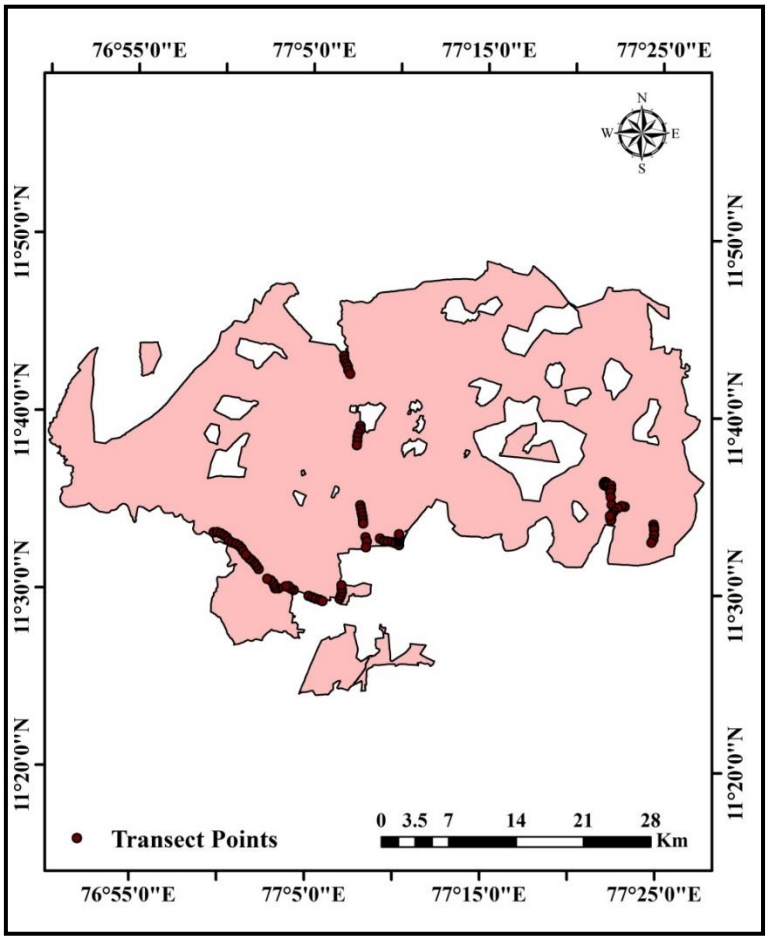


Fig. 5 Map showing Sathyamangalam Tiger Reserve, Sathyamangalam forest division, Western zone of Tamil Nadu

This sanctuary is important as wild life corridor in the Nilgiri Biosphere Reserve between the Western Ghats and the Eastern Ghats a genetic link between the four other protected areas which it adjoins, including the Biligirnaga Samy temple wildlife sanctuary, Sigur plateau, Madumalai National park and Bandipur National park (Aravind, 2011). The study area is located Western agro-climatic zone of Tamil Nadu. Sathyamangalam forest division is one of the largest divisions in the state of Tamil Nadu. The study area extends between longitudes 76.83° and 77.46°; between latitude 11.48° and 11.82°. It consists of five forest types i.e. Tropical Semi Evergreen forest, ii. Tropical moist deciduous forest, iii. Tropical Dry Deciduous forest, iv. Mixed deciduous forest and v. Tropical Dry thorn forest. And also consist of small fragments of high elevation evergreen forest and grassland in Sathyamangalam tiger reserve.

The total area of Sathyamangalam Tiger Reserve is 1411.6 km^2 (545 *Sq.mi*) including, buffer zone 494.33 km^2 and core zone 917.27 km^2. Sathyamangalam forest division includes nine forest tribal settlements and nineteen revenue tribal settlements, but these are settlement not included in Sathyamangalam Tiger Reserves.

In the Sathyamangalam tiger reserve occupied three dominant forest types are the tropical dry thorn forests, the tropical dry deciduous forest, and the tropical moist deciduous forest. Tropical dry deciduous forest are by far the largest vegetation type in the Nilgiri Biosphere Reserves, it constitute 65% of the total area. The tropical dry deciduous forest again divided in to tropical moist deciduous (occupied 18% of total landscape), and tropical dry deciduous forest (occupy 24% of total landscape). Tropical dry thorn forests constitute 20% of the total area of Nilgiri Biosphere Reserve. And tropical moist deciduous forests occupy 10% of total area of Biosphere Reserve.

Climate

The average annual rainfall of in this region over a period of ten year is 824 mm. But it has considerable variation could be noticed from place to place in a sanctuary. The sanctuary lies in the rain fall shadow regions; the bulk of the rain fall is derived more than 70% from North east monsoon during period of September to November. The period from January to April is usually dry, though occasional showers may occur. From May onwards, intermittent rains occur till August. Rain increases slightly between August and September and becomes heavy during October to December and tapers off in January (https://str-tn.org/climate/).

Floral diversity of Sathyamangalam Tiger Reserve

The floristic composition of Tropical Dry Deciduous forest includes *Tectona grandis, Terminalia crenulata, Ougeinia oojeinensis, Diospyros montana* and *Anogeissus latifolia.* The understory includes several shrubs and forbs as well as grass species such *Themeda cymbaria, T. Triandra, Cymbopogon flexuosus* and *Heteropogon contortus* (Suresh *et al*. 1996). Shrubs include *Indigofera pulchella, Helicteres isora* and *Grewia hirsute* etc (Prasad 2012). In addition, *Lantana camara* also occurs across the landscape.

The Tropical dry thorn forests includes, with several species of *Acacia*, including *Acacia chundra* and *A. leucophloea*. Other species include *Ziziphus mauritiana*, *Ziziphus rugosa* and *Ziziphus xylopyrus*. There are also several grass species including *Heteropogon contortus.* Shrubs such as *Ziziphus* spp., *Canthium* spp., and *Randia* spp. are distributed in these forests (Prasad, 2012).

The floristic diversity of Tropical moist deciduous forests includes *Lagerstroemia microcarpa*, *Terminalia crenulata*, *Tectona grandis*, *Dalbergia latifolia*, *Lannea coromandelica*, *Terminalia bellirica* and *Elaeocarpus tuberculatus.* The under canopy consists of both forbs and grass species such as *Themeda cymbaria*, *Imperata cylindrica* and *Cymbopogon flexuosus*. Exotic species such as *Lantana camara*, *Eupatorium odoratum, Ageratum conyzoides*, and *Parthenium hysterophorus* also occur in the landscape.

The deciduous forests, both tropical moist deciduous and tropical dry deciduous, constitute *Anogeissus latifolia*, *Tectona grandis*, and *Terminalia* spp. In addition, there are patches of tropical evergreen forests and high elevation grasslands (Reddy *et al*. 2012).

3. MATERIALS AND METHODS

Vegetation analysis

The study was conducted in three agro-climatic zones of Tamil Nadu, from March 2018 to April 2018. A total of 90 sampling stations were established in threse three zones and assessed the abundances and structure of vegetation. A two-kilometer long transect with six circular plots was a one sampling station. Number of sampling stations per zones was decided based on size of the respective zone and distribution range of invasive species. A total of 20 sampling stations were established in Cauvery delta including Point Calimere Wildlife Sanctuary, 50 sampling stations in the Southern zone and 20 sampling stations in the Western zone that include the Sathyamangalam TR. Transects were laid randomly and maximum tried to lay one transects in each block of District. Further, the same transects were also used assess the abundances birds and other wild ungulates. At each transect, six, 15 m radius plots were laid at an equal intervals of 400 m. Ecological variables such as grass cover, herbs, disturbance level, pellet abundances, bird abundance, presence of ungulates, etc. have been recorded using appropriate methods on the same transect. All other required information related to soil moisture, humidity, temperature, etc were also recorded at each plot.

All plants such as herbs, shrubs and trees were identified with the help of standard floral field guides such as 'An Excursion flora of Central Tamil Nadu, India' (Matthew, 1995), 'Flora of Tamil Nadu series I Volume I' (Nair and Henry, 1983), 'Flora of series II Volume II' (Henry et al., 1987) and 'Flora of Tamil Nadu series III Volume III' (Henry et al., 1989). The binomial of different plants were checked with the International Plant Name Index (IPNI). Using the information obtained from the quadrates, the important quantitative analysis such as density, frequency, and abundance of tree species, shrubs and herbs species were determined as per Curtis and McIntosh (1950). The species richness was calculated by using Margalef's index of richness (Magurran, 1988).

Soil Analysis

Soil samples in this study were collected from the three agro-climatic zones within the transect plots. In each zone, 25 soil samples were collected from triplicate sampling points (each plot 3 samples and mixed into a single sample), at a depth of 10-30 cm. After collection soil samples are transferred to near camp

house for further physicochemical and nutrient analysis, each soil was collected with aseptic safety measures to avoid cross-contamination between the soils and from three different zones.

Socio-Economic Impact Analysis

The influence of *P. juliflora* on socio-economic status was assessed using the questionnaire in selected study sites of entire Nagapattinam (including Point Calimere wildlife sanctuary near villages) and Ramanathapuram district. From two agro-climatic zones, each taluk 75 questionnaires were provided and collect the data. Consumption of Prosopis juliflora seeds by several domestic and wild ungulates like goat/sheep, cattle, chital/spotted deer, blackbuck, feral horse and elephants in entire three agro-climatic zones of Tamil Nadu. To find out invasive and germination behavior of Prosopis juliflora in different ecosystems, measured by the following objectives:

- To estimate the intake of *P. juliflora* pods by ungulates, it is estimated by using dung samples by randomly selected transect plots of entire zone.
- To assess the maturity level of pods in dung samples, and possibilities of germination rate, viability of pods and to calculate the factors influencing pods germination monitored by three different seasons only in field conditions.
- A total seventy five permanent plot (each zone 25 plots) were laid randomly to measure the maturity pods and germination stages from pods to plantlets.

4. RESULTS AND DISCUSSION

The distribution status and their impacts of *P. juliflora* and *Lantana camara* on native biodiversity and socio-economic conditions of local communities were analyzed in three agro-climatic zones of Tamil Nadu. The *Prosopis juliflora* and *Lantana camara* were observed to be affected the both ecological and socio-economic settings of the study area of Tamil Nadu. The field surveys were carried out for one year from August 2017 to July 2018 covering all seasons. The native herbaceous community that occured in the study area were categorized into herbs, shrubs, tree saplings, grasses and others. The diversity of native herbaceous community was comparatively very low in the southern agro-climatic zone where the abundance of *P. juliflora* was very high. The abundances of diversity of native herbs, shrubs and trees was either very low or absent in many sampling plots in the southern zone compared to Cauvery delta zone and western zone of Tamil Nadu (Table. 2). In Fig. 6, Box plot represents the density (mean ± SE) of invasive *P. juliflora* found more in southern zone and it's followed by western zone then Cauvery delta zone.

Distribution patterns and impacts of P. juliflora

Among three agro-climatic regions, southern zone (Ramanathapuram district) was estimated with highest density of *P. juliflora* ($F = 34.35$, $P < 0.05$). Density and frequency of occurrence (%) of *P. juliflora* were higher in southern zone (followed by western zone and Cauvery delta zone. Maximum frequency class 'E' (81-100%) was observed in all three zones whereas minimum frequency class 'A' (1-20%) was observed in western zone and Cauvery delta zone. Southern zone covers 79.4% of *Prosopis juliflora* then western zone (46%), and in Cauvery delta zone (32%). Native species abundance and diversity of other species was higher in western zone followed by Cauvery delta zone and southern zone. In general, the distribution and impacts of invasive *Prosopis juliflora* was higher in drier zone than the wet regions of Tamil Nadu.

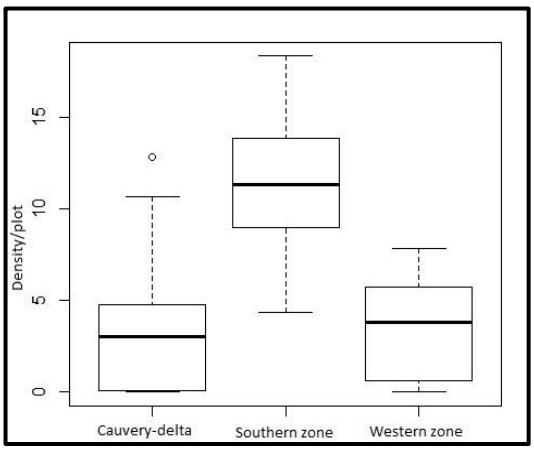


Fig. 6 Density of *Prosopis juliflora* in invaded ecosystems of three agro-climatic zones of Tamil Nadu

Table. 2 Abundance of *Prosopis juliflora* in invaded ecosystem of three agro-climatic zones of Tamil Nadu

S No	Agro-climatic zones	Abundance/plot (± SE)
1	Cauvery Delta zone	7.41 ± 1.63
2	Southern zone	12.99 ± 0.91
3	Western zone	6.21 ± 0.88

It was estimated about 182 trees of *P. juliflora* per hectare from the *P. juliflora* dominated habitat in the southern zone but the estimated desinsity of *P. juliflora* was comparatively low in other zones of Tamil Nadu. Study found that the open areas that were previously used for agriculture or other form of land-use were more conducive for invasion of *P. juliflora* than the forested landscape. This might be possible due to the fact that the open areas or highly disturbed areas are more prone for invasion by alien species as it was reported from elswhere (Ruijven *et al.* 2003). The distribution pattens of *P. juliflora* in Cauvery delta zone, southern zone and western zone of Tamil nadu were revealed in (Fig. 7, 8 and 9).

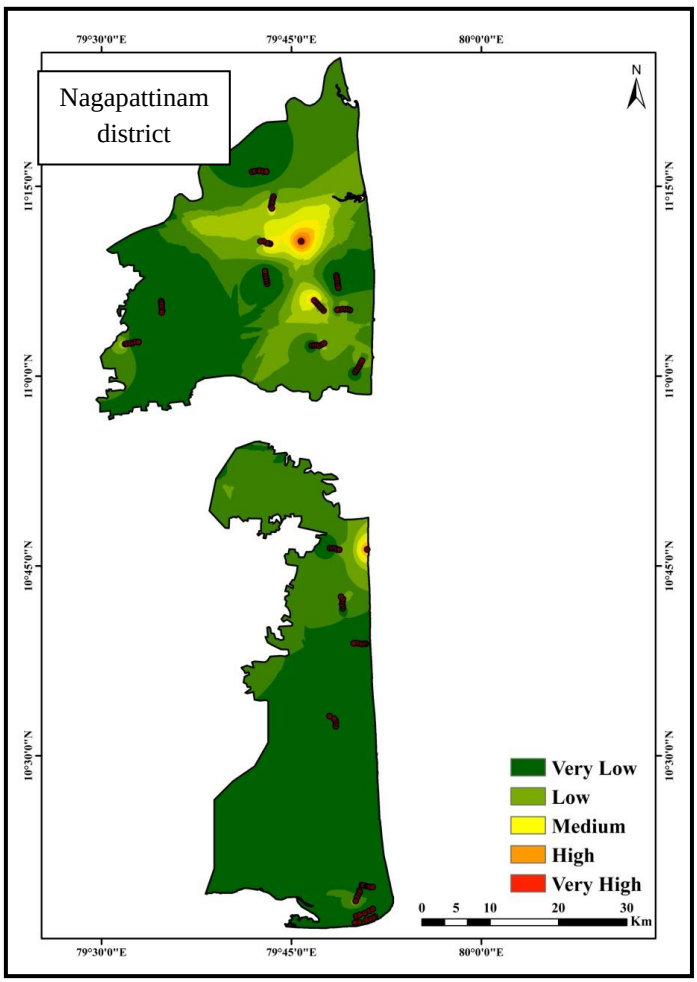


Fig. 7 Distribution and population status of *Prosopis juliflora* in Nagapattinam district,

Cauvery delta zone of Tamil Nadu

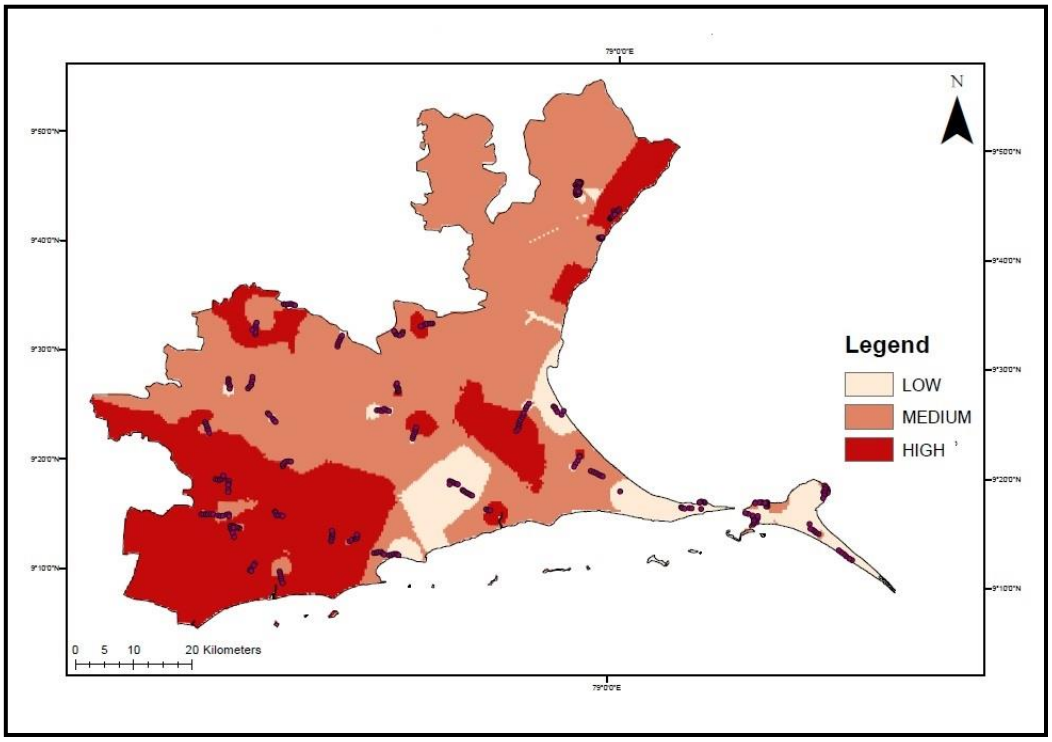


Fig. 8 Distribution and population status of *Prosopis juliflora* in Ramanathapuram district, southern zone of Tamil Nadu

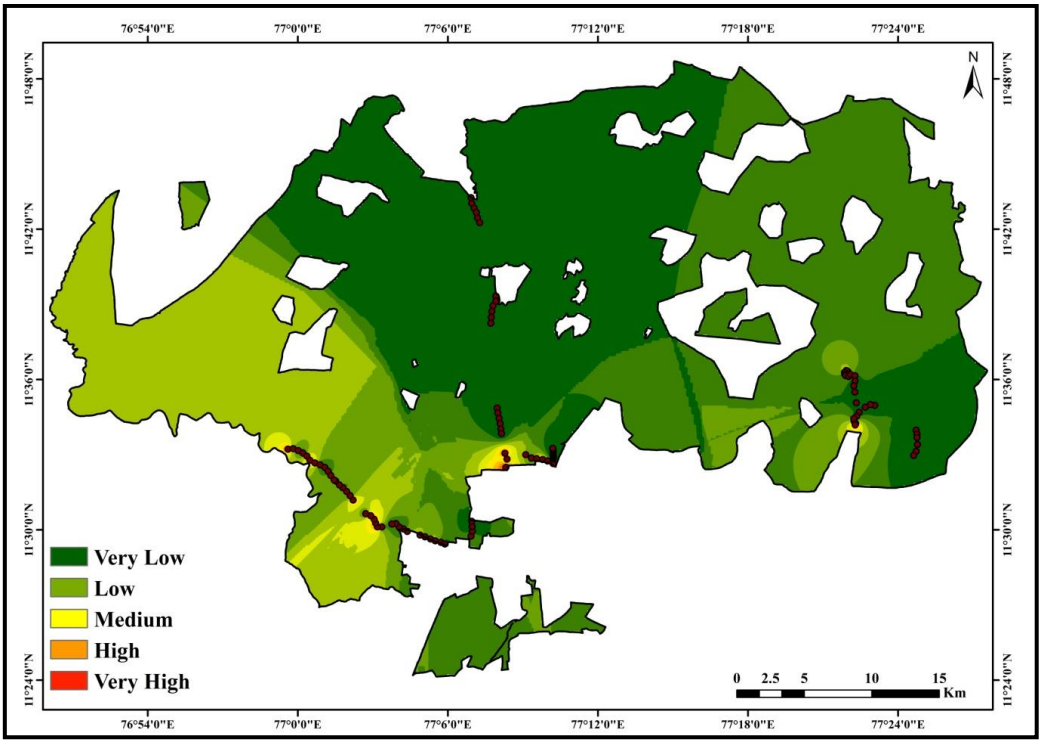


Fig. 9 Distribution and population status of *Prosopis juliflora* in Sathyamangalam Tiger Reserve, western zone of Tamil Nadu

In Cauvery delta zone (i.e. in Nagapattinam district), the Kilvelur, Kuthalam and Thirukkuvalai taluks endure very high abundances of invasive *P. juliflora* (Fig. 7) compare to the other taluks where lands were used for intensive agricultural activites. A total of nineteen species of native plants were recorded in the *P. juliflora* landscape of Nagapatinam district (Fig. 10), largely herbs and tree species.

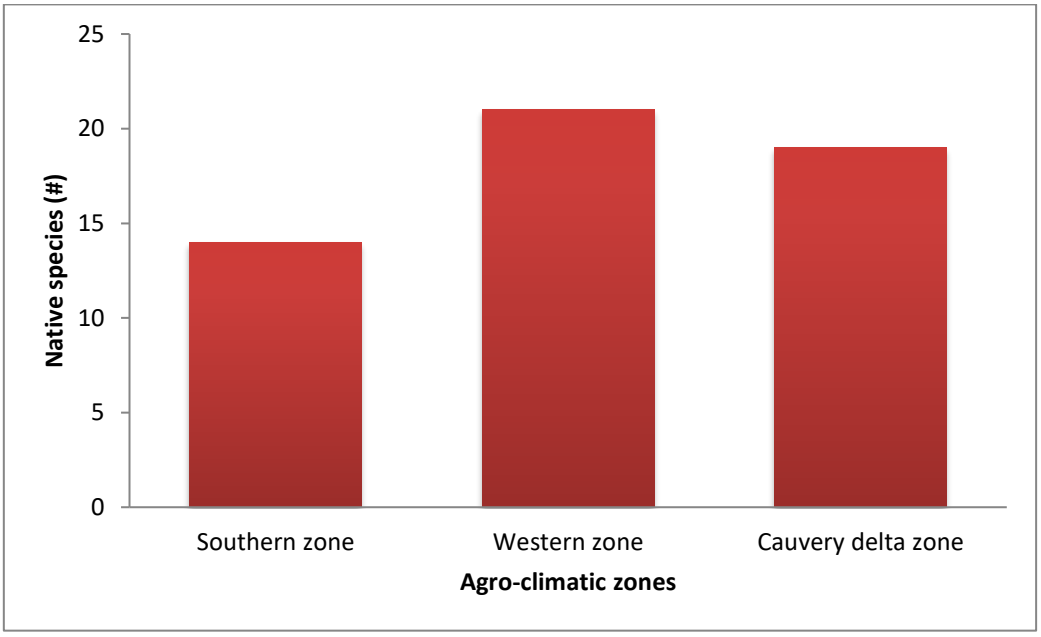


Fig. 10 Occurrence of native species in *Prosopis juliflora* invaded sites of three agro-climatic zones in Tamil Nadu

Vegetation structure in the alien invasive species dominated landscapes

The southern zone i.e. Ramanathapuram was observed with fourteen species of native plants (Table 3) in the *P. juliflora* dominated landscapes. Of these, eleven species were herbs, shrubs and trees, two succulents and one climber. Abundances of native herbs and shrubs were either absent or insignificant in the sampling plots that were highly invaded with *P. juliflora* in the Ramanathapuram District. This might be due to the allelopathy effect of highly dense *P. juliflora* (El-Keblawy and Al-Rawai, 2007). Further, low sunlight fallen on the ground due to thick canopy covery of *P. juliflora* might also be another reason for the low abundance of herbs or shrubs under *P. juliflora.* Moreover, the *P. juliflora* might also affect herbaceous plant cover and abundance through competition (Gibbens *et al*. 1986).

In early 1996, Sivasubramaniyan and Sivaganesan, reported the most common trees occurred in Sathiyamnagalam areas were *Albizia amara, Acacia sundra, A. latronum, A. leucophloea, A. planifrons, Bauhinia recemosa, Cooiphora berryi, Erythroxylom monogynum, Randia dumetron* and *Ziziphus mauritiiana,* and common shrubs were *Cassia auriculata, Capparis* sps.*, Grewia villosa, G. hirsta,* and *Solanum* sp., etc. Invasive exotic plant species such as *Eupphorbia antiquarum*, *Opuntia dellenii* and *Prosopis juliflora* were densely colonized in the elephant corridor of Sathyamangalam tiger reserve. But, we now found that invasive *Prosopis juliflora* and *Lantana camara* were dominating many of the sampling plots and expanded their distribution range in the Tiger Reserve compare to 1996.

Table. 3 List of plant species occurred in *Prosopis juliflora* invaded sites in Ramanathapuram district, southern zone of Tamil Nadu

Plants Name	Name of Family
Cynodon dactylon (L.) Pers	Poaceae
Cyperus rotundus L.	Cyperaceae
Tephrosia purpurea (L.) Pers	Fabaceae
Crotons sparsiflorus L.	Euphorbiaceae
Borassus flabellifer L.	Arecaceae
Cleome viscosa L.	Clemaceae
Calotropis sp.R.Br.	Asclepiadaceae
Azadirachta indica A. Juss. 1830	Meliaceae
Gomphrena globosa L.	Amaranthaceae
Cissus quadrangularis L.	Vitaceae
Opuntia sp. Mill.	Cactaceae
Ricinus communis L.	Euphorbiaceae
Ipomea carnea Jace.	Convolvulaceae
Morinda tinctoria Roxb.	Rubiaceae

Study could report more than 60 species of native flora in the *P. juliflora* dominated areas of the Western zone i.e. Sathyamangalam Tiger Reserve (Table. 4). Seasonal plants such as *Solanum torvum* (Turkey berry) sparsely distributed all over the reserve during the period of monsoon and post-monsoon seasons. Invasive species *Lantana camara* and *Parthenium hysterophorus* inhabit densely in the reserve and replaced several native plants in the Hasanur forest division of this reserve.

The study found that these invasive species have influenced on native vegetation community at the levels of composition, abundances and richness. Singh *et al.* (2008) reported that *Prosopis juliflora* has the negative impact on native plant diversity. It invades the all the habitat types observed in the area and affecting the Acacia woodlands more than others, and changing to *P. juliflora* dominated shrub lands (Getachew *et al.* 2012). *P.* juliflora is also known affect the herbaceous vegetation through shading effect, exerting competition on available resources and moisture, hindering their growth by producing allelo-

chemicals. For example, *P. juliflora* nourishes under storey plants through nitrogen fixation and shading (Ruthven, 2001). Abdillahi *et al*. (2005) stated that in Africa, *P. juliflora* causes loss of many important plant species with natural heritage value. The phytotoxic effects of the fallen leaves of *P. juliflora* also affect the nearby herbaceous community (Sen and Sachwan, 1970). Tidemann and Klemmedson (1973), stated that *P. juliflora* uses two to three times more water than herbaceous vegetation and it has extensively branched lateral roots which exert stronger "pull" on the soil water than the grasses and annuals (Cable, 1976). So the present study sites which it have older trees in invaded sites of all taluks had meagre herbaceous vegetation than younger *Prosopis* trees.

Table. 4 List of plant species occurred in *Prosopis juliflora* and *Lantana camara* invaded sites in Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

Plants Name	Name of Family
Anogeissus latifolia (DC.) Wallich ex Guill. & Perr.	Combretaceae
Albizia amara (Roxb.) B. Boivin	Fabaceae
Pterocarpus marsupium Roxb.	Fabaceae
Albizia lebbeck (L.) Benth.	Fabaceae
Bauhinia racemosa Lam.	Fabaceae
Syzygium tamilnadensis Rathkr. & Chitra	Myrtaceae
Chloroxylon swietenia (Roxb.) DC.	Rutaceae
Terminalia cuneata Roth	Combretaceae
Terminalia chebula Retz.	Combretaceae
Phyllanthus emblica L.	Phyllanthaceae
Phyllanthus acidus (L.) Skeels	Phyllanthaceae
Filicium decipiens (Wight & Arn.) Thwaites	Sapindaceae
Dalbergia latifolia Roxb.	Fabaceae
Dalbergia sissoo Sensu Miq. Synonym of *Dalbergia pseudosissoo* Miq.	Fabaceae
Premna tomentosa Willd.	Lamiaceae
Neolitsea scrobiculata (Meisn.) Gamble Synonym of *Neolitsea pallens* (D. Don) Momiy. & H. Hara	Lauraceae
Euphorbia nivulia Buch.-Ham.	Euphorbiaceae
Euphorbia trigona Haw.	Euphorbiaceae
Euphorbia antiquorum L.	Euphorbiaceae
Euphorbia tirucalli L.	Euphorbiaceae
Carissa carandas L.	Apocynaceae
Diospyros melanoxylon Roxb.	Ebenaceae
Opuntia dillenii (Ker Gawl.) Haw. Synonym of *Opuntia stricta* (Haw.) Haw.	Cactaceae
Cassia fistula L.	Fabaceae
Acacia nilotica (L.) Delile	Fabaceae

Plants Name	Name of Family
Commiphora caudata (Wight & Arn.) Engl.	Burseraceae
Hymenodictyon orixense (Roxb.) Mabb.	Rubiaceae
Melia azedarach L.	Meliaceae
Grewia serrulata DC.	Malvaceae
Ziziphus rugosa Lam.	Rhamnaceae
Cassia auriculata L. Synonym of *Senna auriculata* (L.)Roxb.	Fabaceae
Ageratum conyzoides L.	Asteraceae
Parthenium hysterophorus L.	Asteraceae
Commelina benghalensis L.	Commelinaceae
Rubia cordifolia L.	Rubiaceae
Mollugo pentaphylla L.	Molluginaceae
Mollugo nudicaulis Lam.	Molluginaceae
Mollugo cerviana (L.) Ser.	Molluginaceae
Mollugo cerviana var. *cerviana*	Molluginaceae
Crotalaria pallida Aiton	Fabaceae
Fimbristylis ferruginea (L.) Vahl	Cyperaceae
Fimbristylis dichotoma	Cyperaceae
Fimbristylis cymosa R.Br.	Cyperaceae
Fimbristylis bisumbellata (Forssk.) Bubani	Cyperaceae
Fimbristylis nutans (Retz.) Vahl	Cyperaceae
Fimbristylis aphylla Steud.	Cyperaceae
Fimbristylis dichotoma (L.) Vahl	Cyperaceae
Bulbostylis barbata barbata	Cyperaceae
Bambusa arundinacea (Retz.) Willd.	Poaceae
Bambusa orientalis Nees Synonym of *Bambusa bambos* (L.) Voss	Poaceae
Bambusa vulgaris Schrad. var. *vulgaris*	Poaceae
Bambusa vulgaris Schrad.	Poaceae
Bambusa bambos (L.) Voss	Poaceae
Cyrtococcum pilipes (Nees & Arn. ex Buse) A.Camus Synonym of *Cyrtococcum oxyphyllum* (Hochst. ex Steud.) Stapf	Poaceae
Cyrtococcum patens (L.) A.Camus	Poaceae
Cyrtococcum trigonum (Retz.) A. Camus	Poaceae
Cyrtococcum oxyphyllum (Steud.) Stapf	Poaceae
Oplismenus compositus (L.) P.Beauv.	Poaceae
Oplismenus hirtellus (L.) P.Beauv.	Poaceae
Oropetium thomaeum (L.f.) Trin.	Poaceae
Oropetium villosulum Stapf ex Bor	Poaceae
Oropetium roxburghianum (Schult.) S.M.Phillips	Poaceae
Oropetium capense Stapf	Poaceae
Erythroxylum monogynum Roxb.	Erythroxylaceae
Jatropha curcas L.	Euphorbiaceae

Alien Invasive Species and its impacts on socio-economic status of people

Prosopis juliflora was introduced into many tropical and semi-arid countries as the drought resistant plant and it was seen as a valuable source for fuel wood, livestock, shade, and other in dry lands (Sawal *et al.* 2004; Abedelnoor *et al.* 2009). Seedpods, beans and gum of *P. juliflora* are used as food supplements and medicines for animals in Tamil Nadu as observed in elsewhere in the world (Barba *et al*. 2006; Choge *et al*. 2007). Gatechew *et al.* (2012) reported that *Acacia* woodlands had been covered with forage grass before invasion by the exotics *P. juliflora* in Ethiopia, now these valuable forage grass species have not been observed in *Prosopis* dominated lands. Similar observations were also made in several places of southern and cauvery zones in Tamil Nadu especially in the seasonal wetlands. Most of seasonal wetlands of southern and cauvery zones were habited with native acacia species and these wetlands were used by water birds including migratory birds during monsoon and winter. But these species have now been replaced by P. *juliflora.* Study could observe that many such wetlands were already been under the habitat management programme and the State Forest Department removing this invasive *P. juliflora* to recover the original habitat for birds that needs to be appreciated and supported further. These wetlands can support the livelihoods of local communities through eco-tourism. Forage grasses use to available in these wetlands were very important feed for their livestock of pastoral communities of Ramanathapuram District. In the southern zone, due to lack of sufficient grass species for their livestock, the people experiencing serious fodder shortage and looking for *P. juliflora* as alternate additional livelihoods.

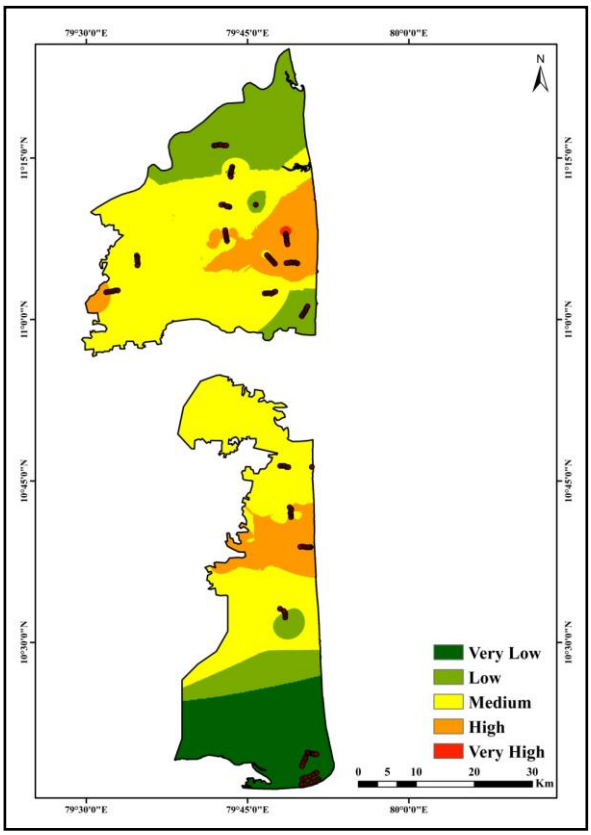
Pods of *P. juliflora* are important foods of domestic cattles and goats/sheeps in the southern zone. A 5 years old *P. juliflora* tree could produce 12 to 65 kg of pods in a year. The *P. juliflora* fuel wood provides monetary support to several people residing in and around the rural villages of Ramanthapuram district. The land owners get benefits from naturally regenerated stands of *P. juliflora* in their uncultivated lands without any investment and labour cost. The labourers derive livelihood support from *P. juliflora* through tree cutting, nearly 30-40 % of people are act as labourers in Ramanathapuram district (Southern zone of Tamil Nadu), and they are all involved in *P. juliflora* tree cutting (Personnel observation). *P. juliflora* yields high value of calorific value (7.854 kcal; calorific values of wood ranges from 3.5 to 5.0 kcal, charcoal ranges from 5.0 to 9.0 kcal) comparable to other charcoal making trees like *Casuarina equisetifolia*, *Acacia mearnsii*, *Acacia polyacantha* and *Acacia xanthophloea*, and other *Acacia* and *Combretum* species (Odour and Githiomi, 2013; Mugo and Ong, 2006) *P. juliflora* is highly preferable tree to charcoal making (Odour and Githiomi, 2004). Because this tree grows on barren, uncultivated,

agricultural, waste lands, is commonly free resources for all people and it's become a major local resources of rural communities. Charcoal manufacturing forms an integral part of daily activities and the revenue earned often plays a vital role in rural livelihoods in Ramanathapuram district. But, *P. juliflora*.was not a favoured economic resource among people of Cauvery and Western zones of Tamil Nadu.

The calorific value of *P. juliflora* was estimated as 4.427 kcal in Tamil Nadu, which is very similar to calorific values of *P. juliflora* from other parts of India (Pasiecznik *et al*. 2001). The superior qualities as firewood are present even in juvenile wood and *P. juliflora* wood burns well even when green (Tewari *et al*. 2000). And the charcoal obtained from the *P. juliflora* was observed to be good quality and it can be produced as easily from young green wood. In Ramanathapuram District, 100 kg of green wood of *P. juliflora* gives about 20 kg of charcoal after the 2 - 4 days of processing by using the traditional charcoal making method. One hectare of pure stand of *P. juliflora* trees in the Ramanathapuram District was estimated to yield approximately 45.9 tonns (± SE 18.4 tns) of biomess that would expected to produce minimum 10 tonns of charcoal/ha.

In India, few State Forest departments are engaged in production and marketing of charcoal predominantly of *P. juliflora*, through special development corporations. From the year of 1986-1993, Gujarat state estimated that they had produced up to 3 million tonnes of charcoal per year, creating an average annual 55500 man-days of employment (Kanzaria and Varshney, 1998). In a single district in northern Peru, charcoal production was estimated at 3000-16000 tonnes per year (Díaz Celis, 1995). *P. juliflora* green wood does not make sparks at the time of burning and emit not much more smoke (Oduor and Githiomi, 2004). So that people believe to promote the *P. juliflora* as a source for smoke-less fuel wood and making of charcoal. *P. juliflora* pods used for animal feed also harvested for firewood, fence posts and construction timbers.

Study could observe the high density of *P. juliflora* invasion was positively correlated with higher abundances of livestock in all three agro-climatic zones of Tamil Nadu. Probably, this might be due to support of livestock in spreading the *P. juliflora* by eating their pods and defecating it. Cauvery delta zone, the distribution of cattle (Fig. 11), goat/sheep (Fig. 12) and hare (Fig. 13) were positively correlated with the distribution of invasive *P. juliflora*.However, in the Point Calimere wildlife sanctuary, blackbucks have been observed using the *P. juliflora* habitat for resting and eating the pods of *P. juliflora* (Fig. 14). Further, *P. juliflora* habitat in the sanctuary was also used by spotted dear (Fig. 15), porcupines (Fig. 16) and wild pigs (Fig. 17) as this species had already replaced the native shrubs of the region.



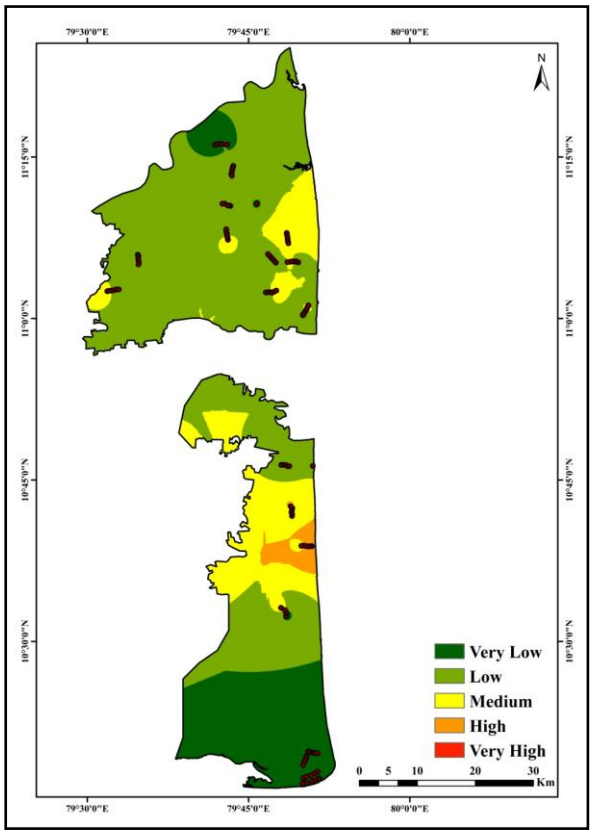


Fig. 11 & 12 Population and distribution status of Cattle (left side) and domestic animals (Goat/Sheep; right side) in *Prosopis juliflora* invaded sites of Nagapattinam district, Cauvery delta zone of Tamil Nadu

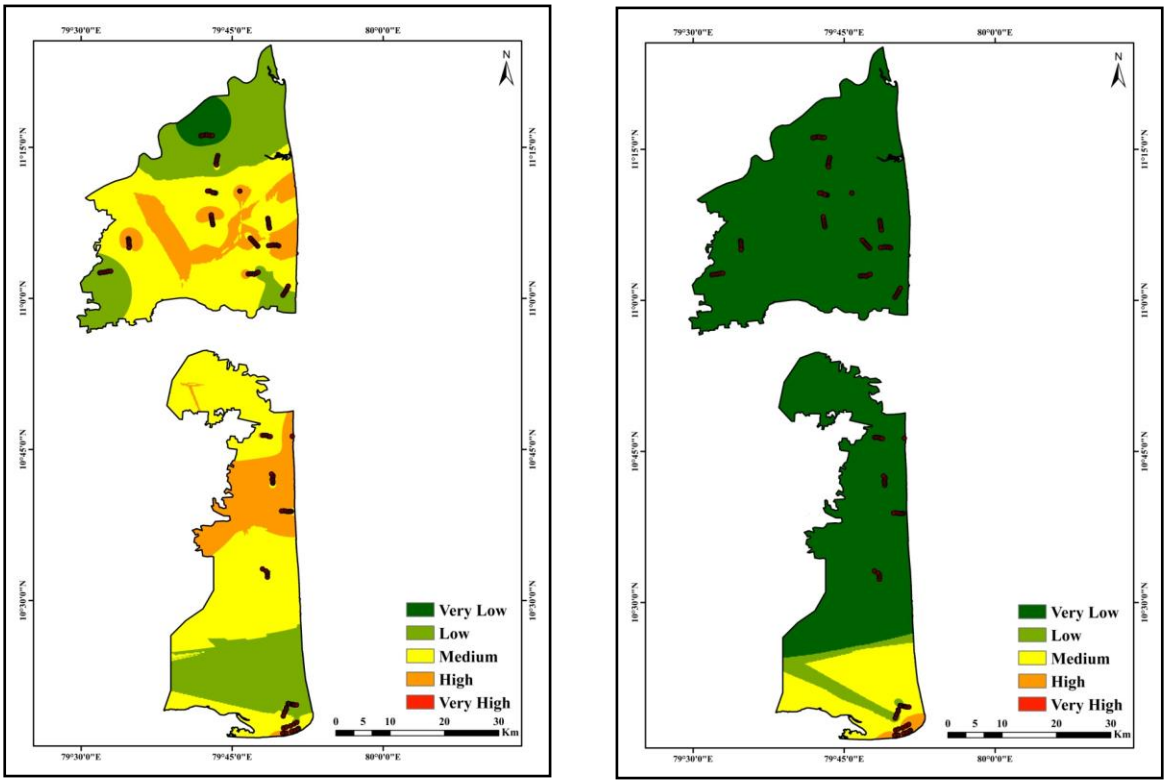


Fig. 13 & 14 Population and distribution status of hare (left side) and Black buck (right side) in *Prosopis juliflora* invaded sites of Nagapattinam district, Cauvery delta zone of Tamil Nadu

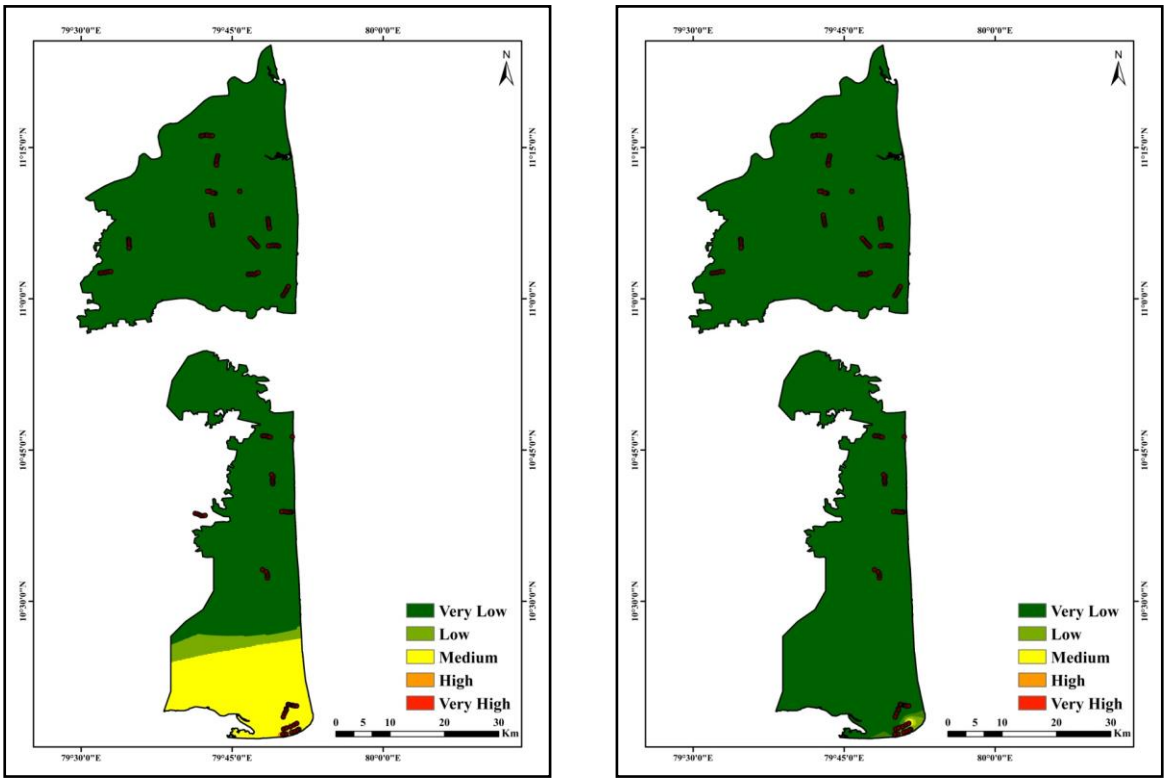


Fig. 15 & 16 Ditribution patterns of Chital (left side) and Porcupine (right side) in *Prosopis juliflora* invaded sites of Point Calimere, Nagapattinam district, Cauvery delta zone of Tamil Nadu

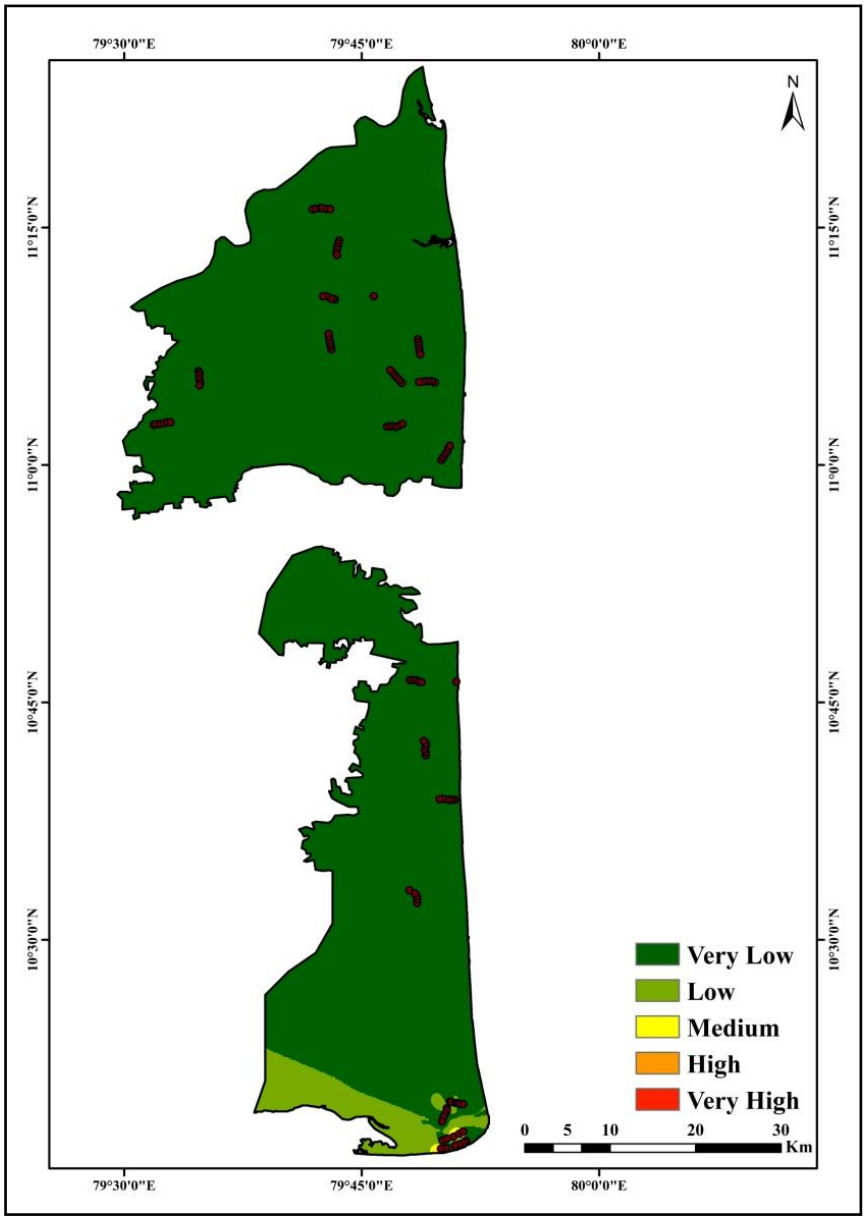


Fig. 17 Population and distribution status of Wild pig in *Prosopis juliflora* invaded study sites of Point Calimere, Nagapattinam district, Cauvery delta zone of Tamil Nadu

The drier southern zone (Ramanathapuram district) supports very few wild mammalian species such as hare (Fig. 18), rats, etc., and good populations of domestic animals like goat/sheep and cattle populations. Semi-arid nature of southern zone is not conducive for good natural vegetation due to low precipitation, soil texture and high wind velocity that normally not favour the growth of dense herbaceous plant communities. However, this zone supports the unique vegetation community comprising *Cocos nucifera*, *Borassus flabellifer* and *Casuarina equisetifolia*.

The western zone supports huge diversity of animals like hare (Fig. 19), goat/sheep (Fig. 20), and other herbivore ungulates like Sambar deer (Fig. 21) Blackbuck (Fig. 22), Chital or spotted dear (Fig. 23) and Elephants (Fig. 24) etc. Western zone (Sathyamangalam) has the huge diversity faunal and floral communities when compare to the southern zone of Tamil Nadu.

Prosopis species have been naturalised in most countries for less than 100 years, this limits the possibility of detailed studies on plant succession. However, a long term study in northern India found *P. juliflora* as the pioneer species in removed or discarded narrow valley (Chinnimani 1998). It proceeded to colonise rapidly, with cover increasing in year two, three, four, five and ten after initial establishment, from 1-5%, 5-15%, 10-20%, 20-50% to 35-90% respectively. It dominated sites under severe biotic and edaphic conditions. After the fifth year, *P. juliflora* gave way to other indigenous species such as *Azadiracta indica*, *Dalbergia sissoo* and *Acacia nilotica*, and in 50-60 years, *P. juliflora* was observed to form only 15-20% of the total tree composition (Sharma *et al.* 1981; in Chinnimani, 1998).

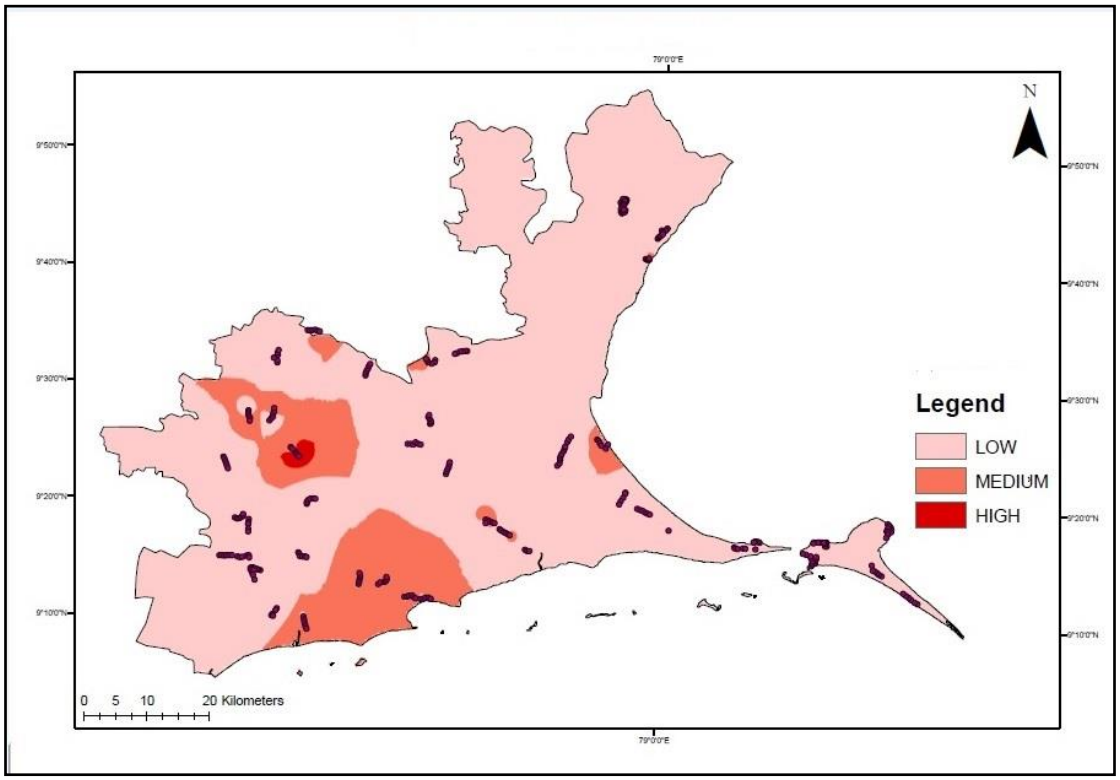


Fig. 18 Population and distribution status of hare in *Prosopis juliflora* invaded sites of Ramanathapuram district, southern zone of Tamil Nadu

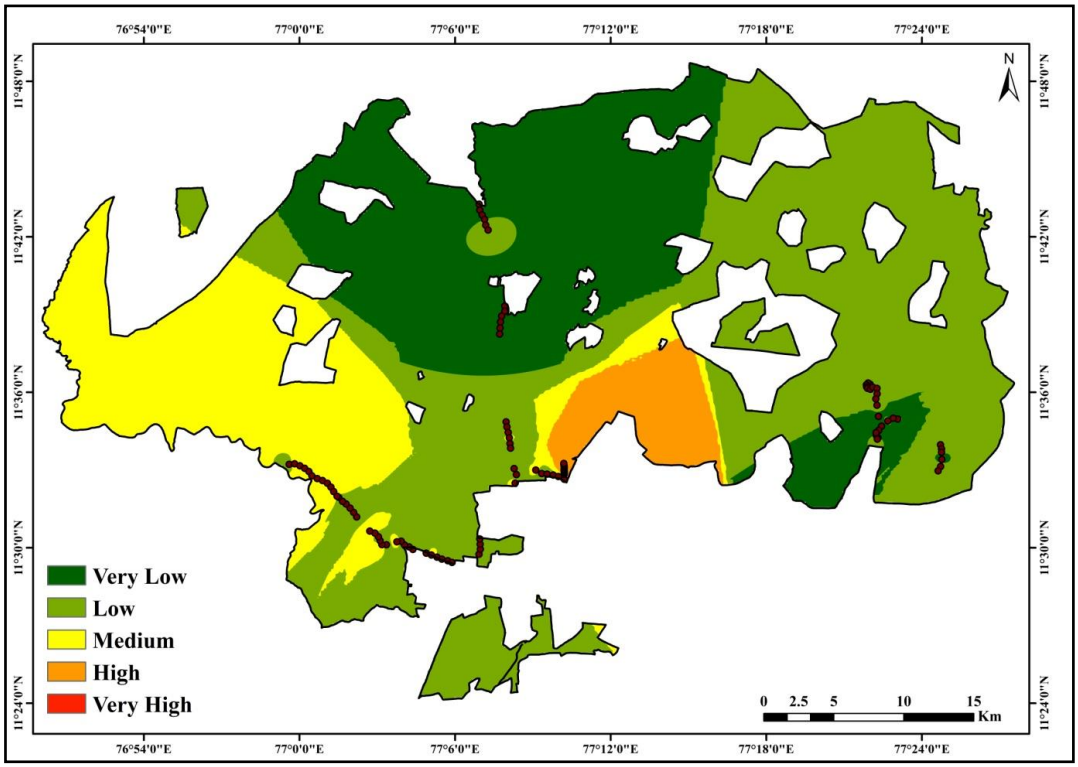


Fig. 19 Population and distribution status of hare in *Prosopis juliflora* and *Lantana camara* invaded sites of Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

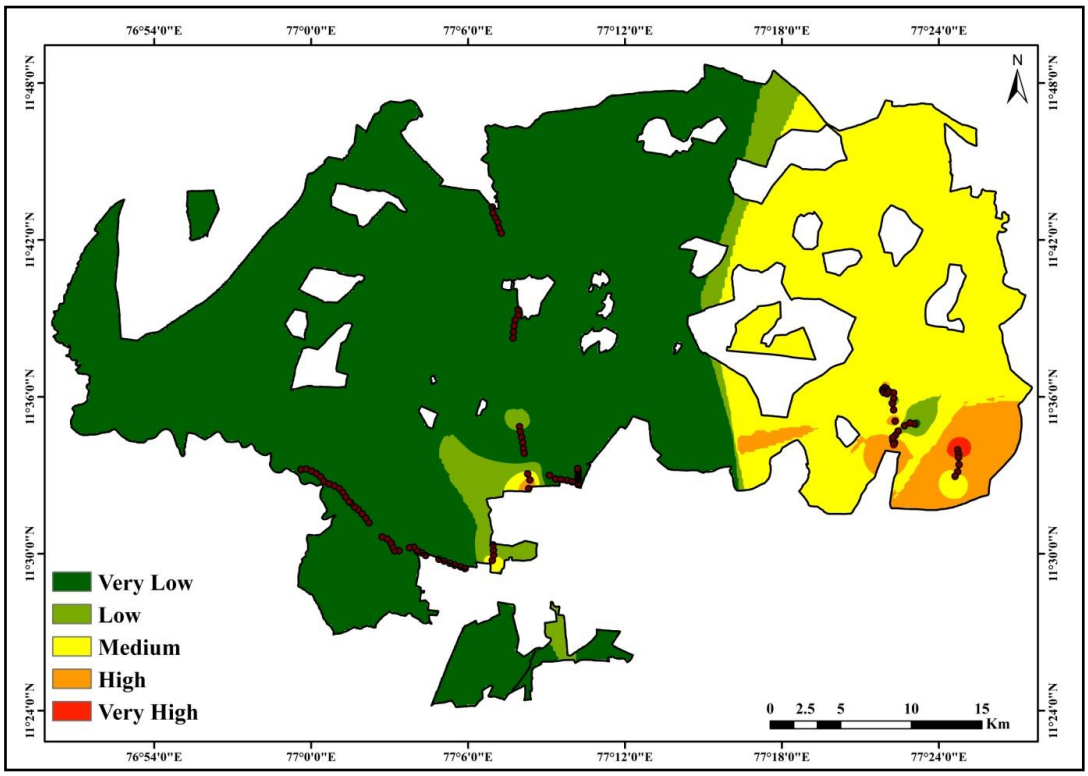


Fig. 20 Population and distribution status of domestic animals (Goat/Sheep) in *Prosopis juliflora* and *Lantana camara* invaded sites of Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

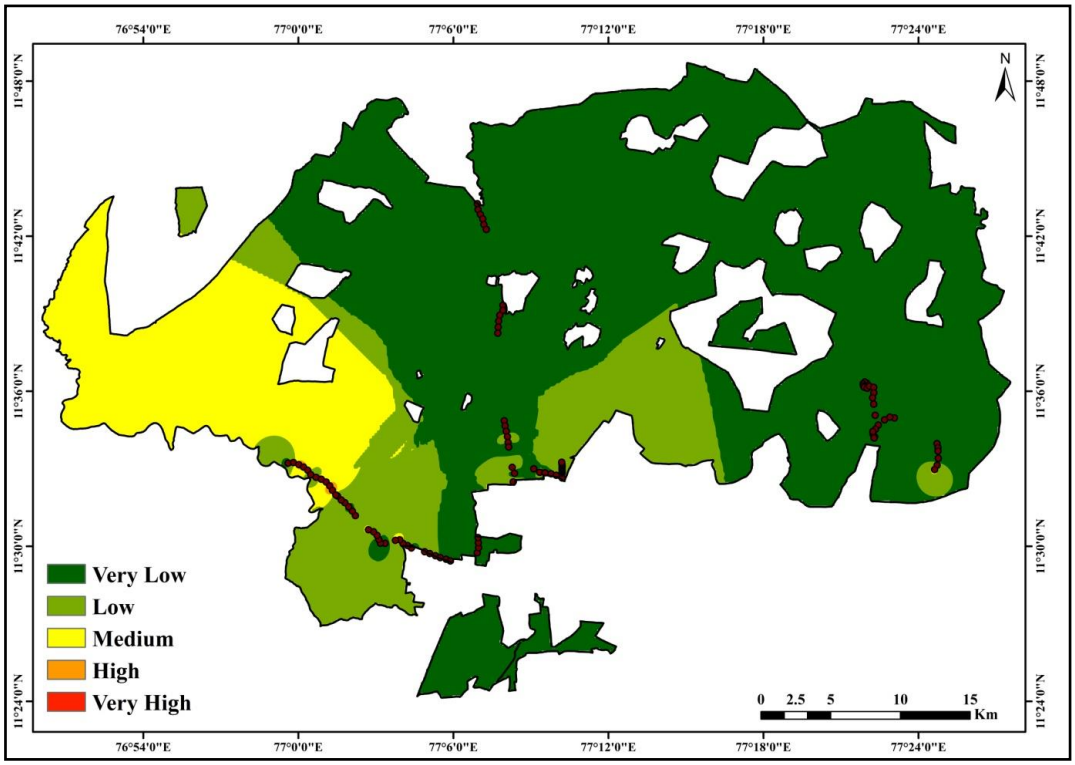


Fig. 21 Population and distribution status of Sambar in *Prosopis juliflora* and *Lantana camara* invaded sites of Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

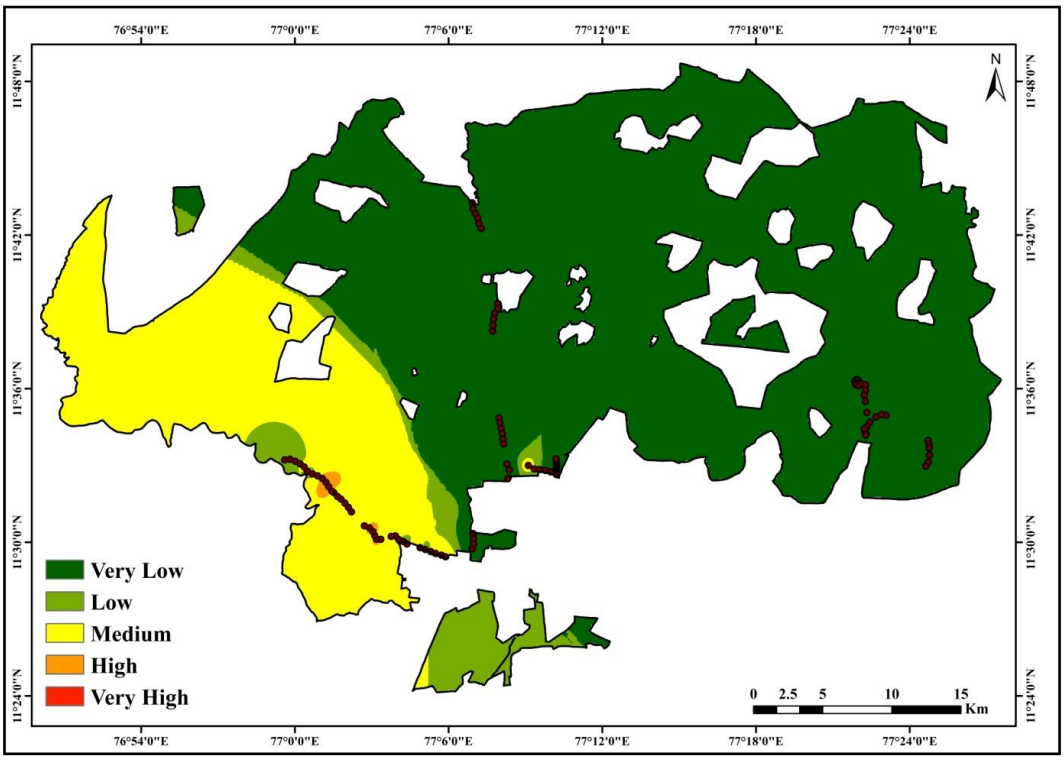


Fig. 22 Population and distribution status of Blackbuck in *Prosopis juliflora* and *Lantana camara* invaded sites of Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

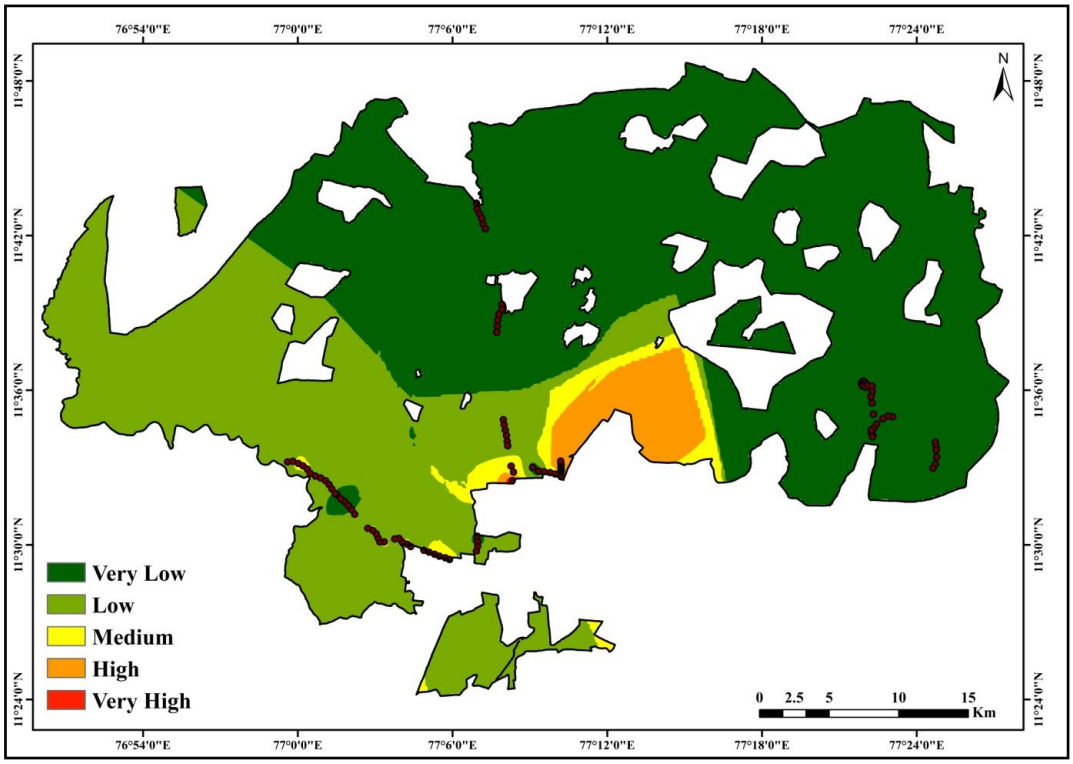


Fig. 23 Population and distribution status of Chital (Spotted deer) in *Prosopis juliflora* and *Lantana camara* invaded sites of Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

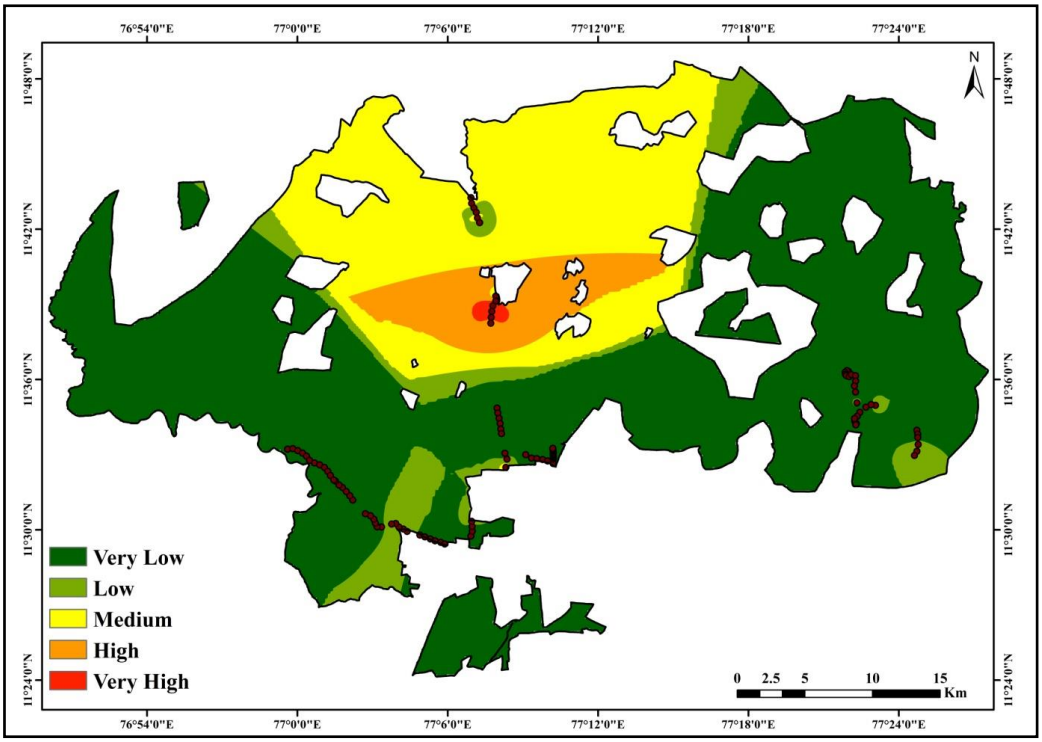


Fig. 24 Population and distribution status of Elephant in *Prosopis juliflora* and *Lantana camara* invaded sites of Sathyamangalam Tiger Reserve, Sathyamangalam forest division, western zone of Tamil Nadu

Prosopis juliflora were important sources for the forage for live stock for the many communities. At the same time, invasion of *Prosopis* reduces grass availability and density stocking by live stock. (Gatechew *et al.* 2012). The density of invasive species positively correlates with occurrence of livestock (Fig. 25). The presence of livestock calculated using pellet count available in the selected study sites (Fig. 25). The matured ripe seed pods are highly palatable to all local ruminant species such as cattle, sheep, camel, buffalo, rabbits etc. (Sawal *et al.* 2004). Population of hare was higher in western zone followed by Cauvery delta zone then southern zone (Fig. 25) this is due to presence of high density and abundance of invasive species *P. juliflora*. Choge *et al.* (2002) and Mooney *et al.* (2001) reported that *Prosopis* seedpods are sweet, nutritious and have low concentration of tannins and other unpalatable chemicals and have moderate to high digestibility of grazing animals.

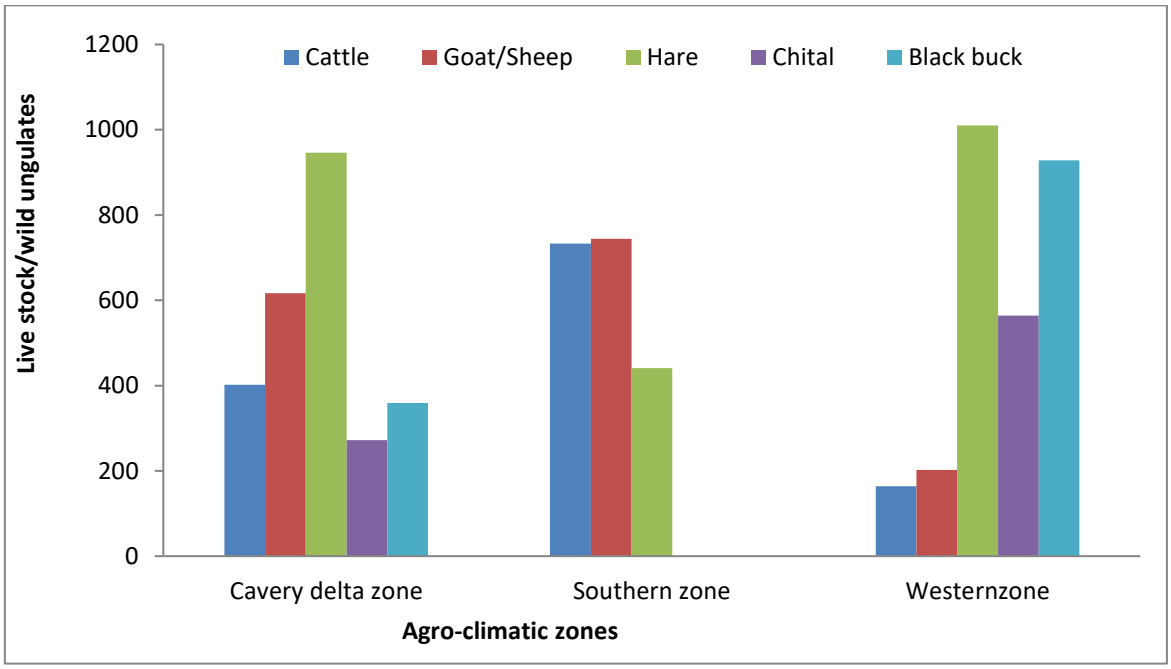


Fig. 25 Presence of livestock and wild ungulates in *Prosopis juliflora* invaded sites of three agro-climatic zone of Tamil Nadu

In natural grazing lands where *Prosopis* seedpods are abundant, livestock consume the seedpods voluntarily during grazing and browsing. In many species the seedpods contain a sweet, dry, yellow pulp and the seeds contained in the pods are high in protein 34-39% (Gutteridge and Shelton, 1998) and therefore it plays a big role as a nutritious feed to animals and hens (Silva 1986 and Wahome *et al.* 2008). *P. juliflora* starts fruiting at the age of 3 to 4 years; ten year old plant may yield up to 90 kg of seedpods annually (Anonymous, 1969). Mendes (1986), reported that a well matured individual tree may yield 169 kg of seedpods per annum. So the production of seedpods from the whole India has been

estimated to be two million tonnes per annum (Punj, 1995). It does indicate availability of a large feed resource that may be used by feed processing industries for livestock. Seedpods are used to incorporate the feeds of livestock and poultry products commonly obtainable in South America, Africa and India (Sawal *et al.* 2004).

Alien invasive species and wildlife

Relative abundances of birds such as *P. cristatus, C. coturnix* and *A. tristis* were positively correlated with *Prosopis juliflora* invaded taluks of Ramanathapuram district, southern zone of Tamil Nadu (Fig. 26). *P. juliflora* provide shelter and breeding sites of several migratory birds. For example, Chitrangudi Bird sanctuary situated in Mudukulathur taluk, Ramanathapuram district and Vettangudi Bird sanctuary situated in Sivagangai district, are the pioneer nesting places for several migratory and wetland birds (Chandrasekaran *et al.* 2014) in Table 5. Chandrasekaran *et al.* (2014), reported that *P. juliflora* poses significant threat to the nesting success of wetland birds in Vettangudi bird sanctuary, south India.

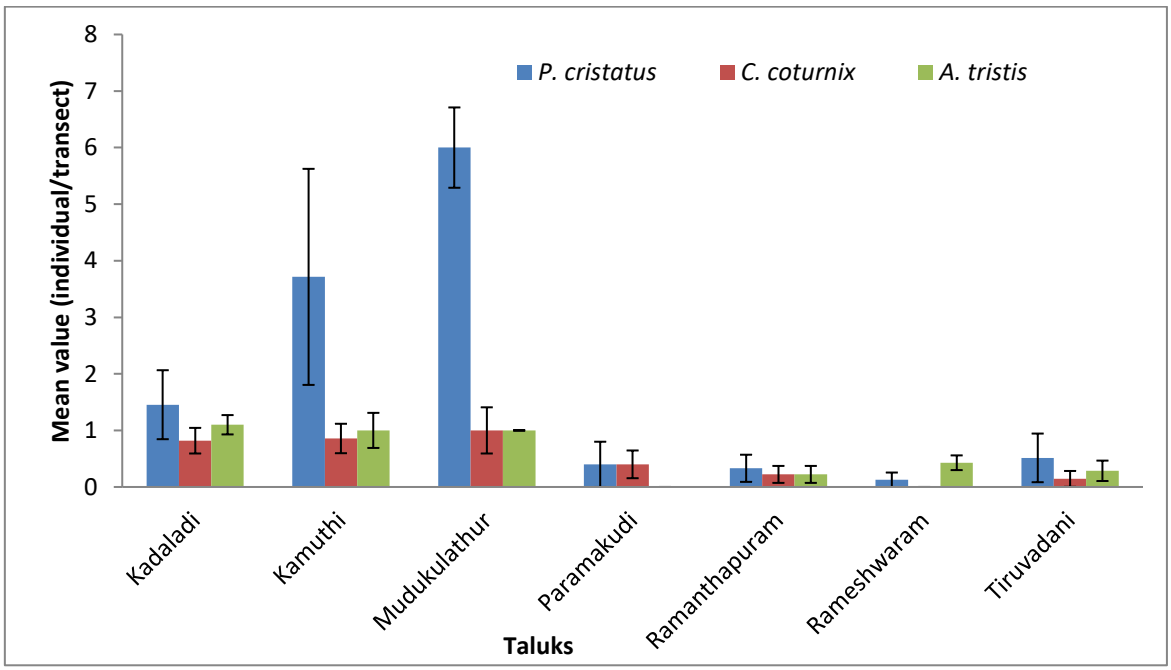


Fig.26 Mean value and population status of birds in *Prosopis juliflora* invaded ecosystems of Ramanathapuram district taluks, southern zone of Tamil Nadu

Table. 5 List of wetland birds in Vettankugudi bird sanctuary, Sivagangai district of Tamil Nadu (Source: Chandrasekaran *et al.* 2014).

Zoological name	Common name	IUCN status	Family	Distribution range
Anhinga melanogaster	Darter, African Darter and oriental Darter	NT	Anhingidae	Bangladesh, Cambodia, India, Indonesia, Lao People's Democratic Republic, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka and Vietnam
Microcarbo niger	Little cormorant	LC	Phalacrocoracidae	Asia, Europe, Africa and America
Nycticorax nycticorax	Black-crowned night heron	LC	Ardeidae	United States, Central America and West Indies
Ardea cinerea	Grey Heron	LC	Ardeidae	Native throughout temperate Europe and Asia, and also parts of Africa
Ardeola grayii	Indian pond heron	LC	Ardeidae	South African countries, Burma, Bangladesh, Malaysia and Singapore
Bubulcus ibis	Cattle Egret	LC	Ardeidae	North America, Spain, Portugal, Asia, Africa and Europe
Ardea alba	Great White Egret	LC	Ardeidae	North and South America, Asia and Australia
Mesophoyx intermedia	Intermediate Egret, Yellow-Billed Egret	LC	Ardeidae	Oceania, Africa, Asia and Australia
Egretta garzetta	Little Egret	LC	Ardeidae	Europe, Africa, Asia and Australia
Anastomus oscitans	Asian Open-bill	LC	Ciconiidae	Tropical southern Asia
Plegadis falcinellus	Glossy Ibis	LC	Threskiornithidae	Europe, Africa, Asia, Australia, Atlantic and the Caribbean region of the Americas
Threskiornis melanocephalus	Black-headed Ibis	NT	Threskiornithidae	Bangladesh, Cambodia, China, Hong Kong, India, Indonesia, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Sri Lanka, Thailand and Vietnam
Himantopus himantopus	Black-winged Stilt	LC	Recurvirostridae	South Asian countries, Africa and America
Actitis hypoleucos	Common Sandpiper	LC	Scolopacidae	Temperate and subtropical region of Europe and Asia and America
Anas querquedula	Garganey	LC	Anatidae	Africa, Asia and Australasia
Tachybaptus ruficollis	Little Grebe	LC	Podicipedidae	Europe, Asia and Africa
Amaurornis phoenicurus	White-breasted Water hen	LC	Rallidae	Asia

NT, Near threatened; LC, Least concern.

Allelopathic effects of P. juliflora

In all zones that were studied in Tamil Nadu, both *P. juliflora* and *Lantana camara* were observed to be allelopathic that discouraged other native plants from growing around them and seems to be toxic to other biotas in ways that allow the invasives to monopolize the space, sunlight, and nutrients at the exclusion of other species. Plant diversity was observed significantly low at *P. juliflora* and *Lantana camara* dominated habitats than other habitats of Tamil Nadu including in the Ramanathapuram District. In the native habitats of *P. juliflora*, the other species have developed a mechanism to counter the allelopathy of *P. juliflora*, but such defense seems to be not available to several native plants of Tamil Nadu.

Noor *et al.* (1995) reported that aqueous extract from under canopy soil and different parts of *P. juliflora* inhibit the germination and early seedling growth of various cultivated plants of *Zea mays*, *Triticum aestivum* and *Albizia lebbeck*. In Gatechew *et al.* (2012) explained parts of leaf, bark and root aqueous extract were control the effects on germination percentage, seedling growth of several native plants like *Acacia nilotica* (L.) Willd. ex Del., *Acacia tortilis* (Forssk.) Hayne, *Cenchrus ciliaris* L. and *Enteropogon rupestris* (J.A. Schmidt) A. Chev. Jayasinghe and Perera (2011), demonstrated seed germination on six

forest native plants (*Bauhinia racemosa, Cassia occidentalis, Drypetes sepiaria, Flueggea leucopyrus, Salvadora persica* and *Ziziphus mauritiana*), by using different plant parts extraction of *P. juliflora,* which cause the result clearly indicated that, root extraction of *P. juliflora* can affect the seed germination of native plants. Al Humaid *et al*. (1998) recorded that suppression of seed germination and early growth of Bermuda grass (*Cynodon dactylon*), and Kaur *et al*. (2014) reported that *Brassica campestris*, by aqueous extracts of *Prosopis* leaves. Goel *et al*. (1989) found that leaf extracts as well as leaf leachates of *P. juliflora* carried allelochemicals, so did decaying leaves. These authors, as well as Chellamuthu *et al.* (1997), who studied the influence of *P. juliflora* leaf litter on the germination of seeds of other species, attributed the allelopathy to phenolic compounds present in *P. juliflora*.

The allelopathic effect of *P. juliflora* leaf litter is due to the presence of some phenolic compounds (Chellamuthu *et al*. 1997). Leaf aqueous extracts of *P. juliflora* retarded root and shoot growth of *Cyanodon dactylon* (Al Humid and Warrag, 1998), and *Lepidium sativum* L. (Nakano *et al.* 2004). Leaves extract have higher allelopathic compounds than reoots and bark, while bark seems to have the least compounds (Gatechew *et al.* 2012). In pot studies examining the allelopathic effect of *P. juliflora* leaf litter, (Chellamuthu *et al*. 1997) indicated that germination of *Vigna mungo, Sorghum bicolour* and *P. juliflora* was significantly reduced with the maximum reduction occurring at 2% incorporation of *P. juliflora* leaf litter. Therefore *P. juliflora* affects the vegetation found in the invaded lands, especially annuals. These studies indicated that *P. juliflora* foliage may contain water soluble allelochemicals, which get leached to the ground as rain water falls on them and tickles down (Abbasi and Abbasi, 2011). These allelo chemicals were isolated by Nakano *et al*. (2002, 2003, 2004) and identified as *syringin*, (-) - *lariciresinol*, *L- tryptophan*, *juliprosopine*, *juliprosine*, and *juliprosopinal*. Among these, *juloprosine* derivatives exhibited the most pronounced allelopathic effect.

It also displays auto toxicity and its leachates suppress the germination of its own seeds (Warrag 1994, 1995). This is, possibly, one of the survival strategies with which *P. juliflora* prevents its sister trees to grow so close to it that they may jeopardize each other's nutrient and water availability (Patnaik *et al.* 2017).

Alien invasives species and people

Based on our questioner survey, there was no significant difference between people who like and dislike the economic values of *P. juliflora* (Fig. 27) in Ramanathapuram district but peole did not like the *P. juliflora as much* in the Nagapattinam district (Fig. 28), i.e. Cauvery delta zone of Tamil Nadu although it has some economic values. Socio-economic impact and status of *P. juliflora* in seven taluks in

Ramanathapuram district and Cauvery delta zone was provided in Fig. 29 & 30. In western zone there was no possibility of collecting the socio-economic data taluk wise, therefore, we could collect these data in tribal settlement areas and nearby villages of Sathyamangalam Tiger Reserve. Interview with local communities revealed that the prosopis has been sperading at faster rate in the Tiger Reserve as it does not require any special conditions to germinate the seeds and out compete to native species (Raghubansi *et al.* 2005). Compared to other plant species such as *Acacia nilotica*, *A. auriculiformis*, *A. tortils* and *Terminalia arjuna, P. juliflora* produce high quality of fuel wood, it suitable for short harvest rotation cycle and it has high wood density, biomass, low ash, good combustion heat in a juvenile stage. *Prosopis juliflora* had highest Fuel wood Value Index (FVI: High calorific value and density, and low water and ash content account for high FVI). This study found that more than 90% of people uses *P. juliflora* as the sources of fuel wood and making of charcoal in the southern zone of Tamil Nadu.

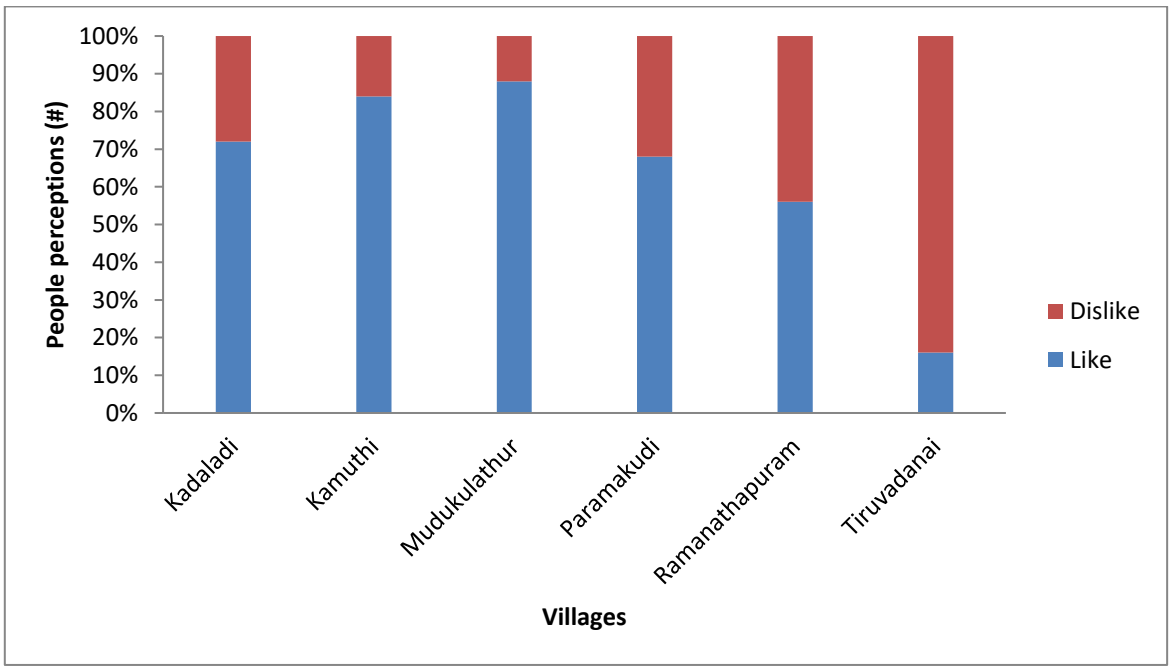


Fig. 27 People perceptions in impact of socio-economic status of *P. juliflora* in seven taluks in Ramanathapuram district, southern zone of Tamil Nadu

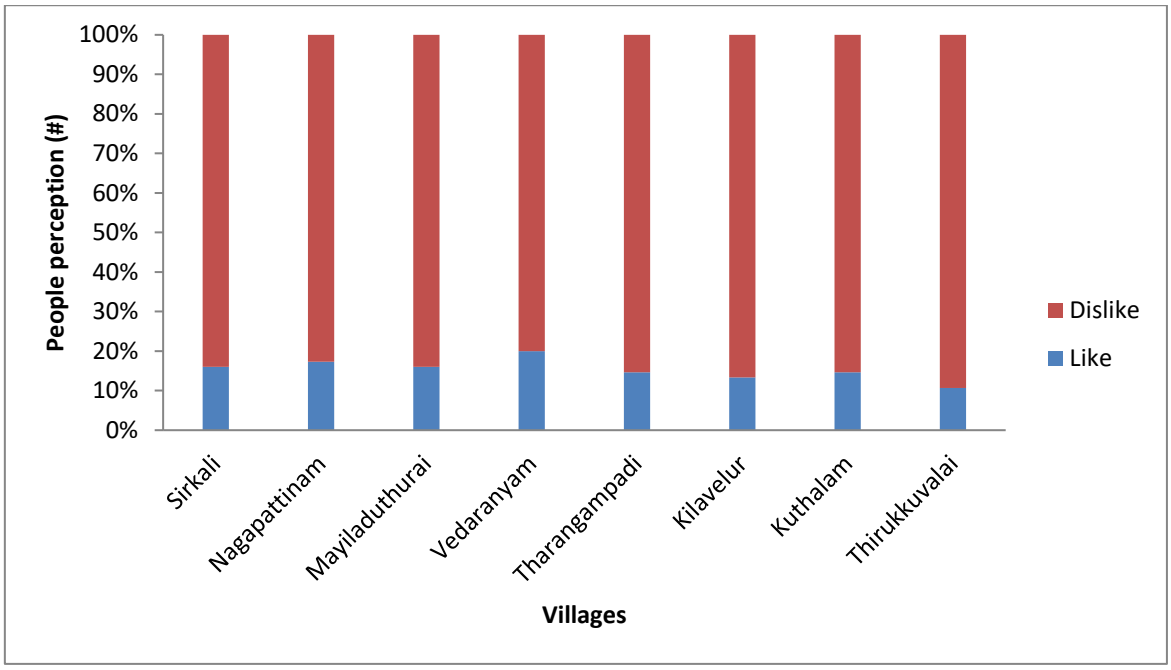


Fig. 28 People perceptions in impact of socio-economic status of *P. juliflora* in eight taluks in Nagapattinam district, Cauvery delta zone of Tamil Nadu

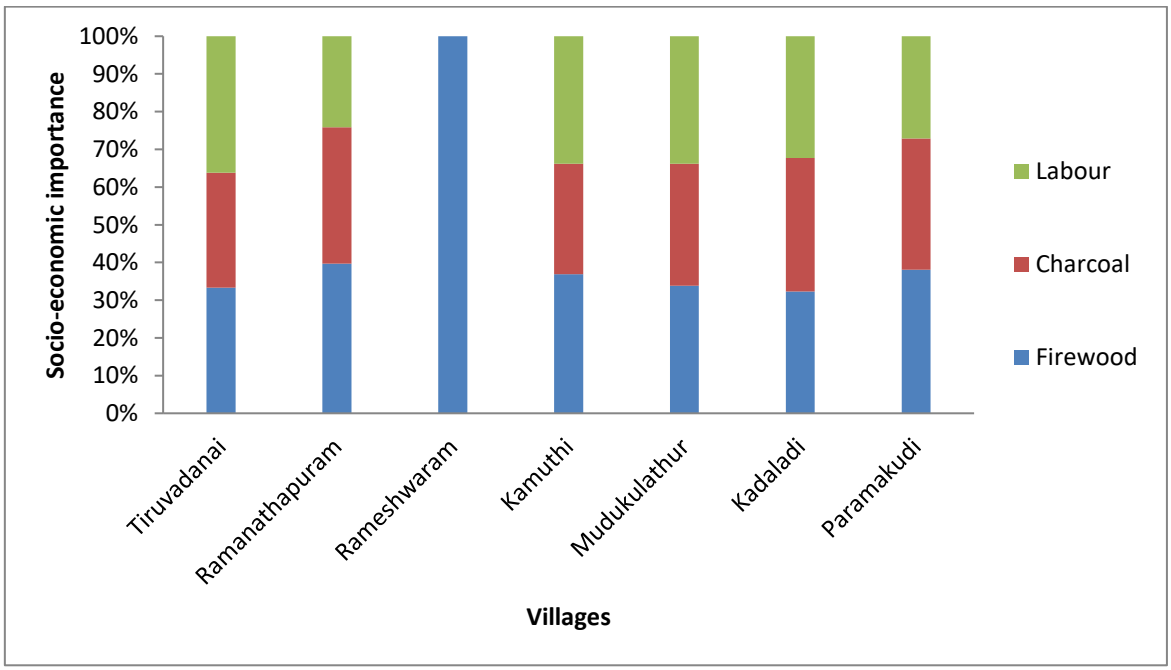


Fig. 29 Socio-economic status of *P. juliflora* in seven taluks in Ramanathapuram district, southern zone of Tamil Nadu

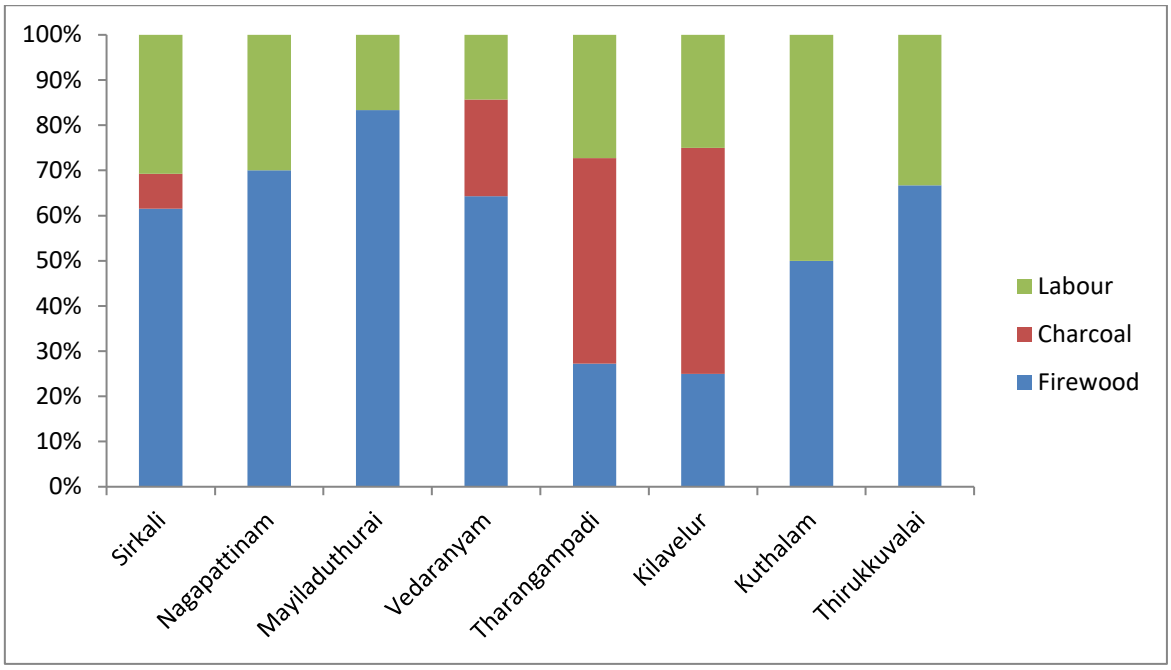


Fig. 30 Socio-economic impact of *P. juliflora* in eight taluks in Nagapattinam district, Cauvery delta zone of Tamil Nadu

In Tamil Nadu, the trees outside forests (TOF) are estimated to be contributing 41% of the total fuel wood supply. According to study that was completed in 2013, the total demand for fuel wood varied between 15.17 to 23.22 million cu/m in Tamil Nadu. In house hold sector requires 84.5 % of total fuel wood demand; it continues to dominate with contribution ranging between 70% to 80%. (Tamil Nadu State Action Plan for Climate Change, 2013). The Wood Balance Study for Tamil Nadu (2009) assessed that the total demand for wood in Tamil Nadu for the year 2008 was 28.5 million cu/m, of which, fuel wood constituted 82 % of the total demand. Tamil Nadu households and industries demand accounts for 77 % and 16 % respectively of the total demand for wood. *P. juliflora* was fulfilled the major demand of fuel woods in these three zones.

5. PHOTO PLATES OF STUDY SITES

I. *Prosopis juliflora* invaded ecosystems, **a.** Cauvery delta zone; **b.** Point Calimere wildlife sanctuary; **c.** southern and; **d.** western zones of Tamil Nadu

II. Villagers removed *Prosopis juliflora* from invaded ecosystems and used as fuel wood

I. Making and production of Charcoal in *kiln* from *Prosopis juliflora*, southern zone of Tamil Nadu

II. Before **a** and after **b** eradication of *Prosopis juliflora,* emergence of native vegetation in study plot of southern zone of Tamil Nadu

III. *Prosopis juliflora* act as shading and feeding ground for live stocks in southern zone of Tamil Nadu

Prosopis juliflora act as shading and feeding ground for wild ungulates, **a.** spotted deer; **b, c.** feral horse; **c, d.** blackbuck in Cauvery delta, western zones of Tamil Nadu

5. CONCLUSIONS

Management strategies for P. juliflora and Lantana camara

The study could analyse the spread, ecological aspects and socio-economic aspects of *P. juliflora* invasion in Tamil Nadu especially at three important agro-climate zones including the Sathyamangalam Tiger Reserve. It was found that wetlands in the arid region are highly susceptible to Prosopis invasion and these wetlands were once used by migratory birds in large numbers but not nowadays that is might be due to high abundances of invasive species. Wild animals seemed to be play a major role in spreading the invasive species inside the forested landscape whereas in the Southern Zone and Cauvery Delta the both domestic and wild animals (largely birds) responsible for spread of these invasive species. Although, alien invasive species such as *P. juliflora and L. camara* are adversely affecting the native biodiversity especially in the Western Zone and Cauvery Delta but it has livelihood values in the Southern Zone especially Ramanathpuram and adjoining districts of Tamil Nadu.

Therefore, the study concludes that complete eradicaton of *P. juliflora and L. camara* is inevitable in the forested landscapes and Proteccted Areas of Tamil Nadu. However, the study recommend that sustainable management and control of *P. juliflora* may be a better solution than eradication in the Southern Zone.

Further, the study observed that the clearing invaded land and continuously using it for crop farming would reduce the invasion in the Southern and Cauvery Delta zones. The study also found that the available nitrogen, phosphorus and organic carbon in the soil were high in highly invaded areas compared to less or non-invaded sites especially in the Southern Zone. However, the basal cover of native herbaceous vegetation and native tree diversity were found to be much reduced under high *P. juliflora- L. camara* invaded areas. Results from economic analyses also revealed that the benefits of the *P. juliflora* invasion in the southern zone are higher than the costs. However, some aspects such as increased risk of water table and long-term ecological changes were not examined, thus making the total economic valuation incomplete.

Extensive efforts are required to control *P. juliflora and L. camara,* by chemical, biological, and mechanical means. There is no strategy to even control these weeds; let alone eradicate them, has achieved any enduring success especially inside the Protected Areas and forested landscapes. At best *P. juliflora and L. camara* spread can be halted by actions such as clear cutting/up-rooting followed by burning of the stump of *P. juliflora* and keeping up-side down of stump of *L. camara*. Alternatively, ways can be found to utilize the existing stands of *P. juliflora* so that frequent harvesting can exert a check on its expansion. Minimum, 10 years weed management plan should be made mandatory of all Management

Plans of all Protected Areas and other reserve forests of Tamil Nadu to successfully halt the expansion of these invasive species so that the native biodiversity are conserved.

6. REFERENCES

1. Abbasi, S.A. and Nipaney, P.C. 1986. Infestation by aquatic weeds of the fern genus salvinia - its status and control. *Environmental Conservation*, 13, 235–241.
2. Abbasi, T. And Abbasi, S.A. 2011. Sources of pollution in rooftop rainwater harvesting systems and their control. Critical *Reviews in Environmental Science and Technology*, 41, 2097–2167.
3. Abdillahi, A., Aboud, P., Kisoyan, K. and Coppock, D.L. (2005). Agro-Pastrolists Wrath for the *P. juliflora* Tree: The Case of the *Ilchamus* of Baringo District. Pastrol risk Management Project, Kenya.
4. Abedelnoor, T.M., Talib, N.H., Mabrouk, A.A., Mohamed, M.A., El-Mahi, M.I., Abu-Eisa, H.H., Fre, Z. and Bekrezion, H. 2009. The use of alternative animal feeds to enhance food security and environmental protection in the Sudan (The case for *Prosopis juliflora*). Ph.D., thesis, Sudan, pp. 1-38.
5. Abohassan, A.A. Kherallah, I.E. and Kandeel, S.A. 1988. Effect of sewage effluent irrigation regimes on wood quality of *Prosopis juliflora* grown in Riyadh Region. *Arab Gulf Journal of Scientific Research*, B6, 45-53.
6. Aggarwal, R.K. 1998. Effect of *Prosopis* species on properties of arid zone soils. . In: *Prosopis* Species in the Arid and Semi-Arid Zones of India (Eds. Tewari, J.C., Pasiecznik, N.M. Harsh, L.N. and Harris, P.J.C.), Proceedings of a conference held at the Central Arid Zone Research Institute, Jodhpur, Rajasthan, India on November 21-23, 1993. The *Prosopis* Society of India and the Henry Doubleday Research Association and CZARI, Jodhpur, India.
7. Ahmed, P. 1991. Agroforestry: a viable land use of alkali soils. *Agroforestry systems*, 14, 23-37.
8. Al-Humaid, A.I. and Warrag, M.O.A. 1998. Allelopathic effects of mesquite (*Prosopis juliflora*) foliage on seed germination and seedling growth of Bermuda grass (*Cynodon dactylon*). *Journal of Arid Environments*, 38, 237–243.
9. Aravind, K.B. (2011). Sathyamangalam Wildlife Sanctuary expanded to 1.41 lak hectares. The Hindu, Chennai (Chennai, India: Kasturi & Sons Ltd). 27 September; Retrieved 2011-09-27.
10. Archer, S. 1989. Have southern Texas savannas been converted to woodlands in recent history? *The American Naturalist*, 134, 545–561.

11. Australian Weeds Committee, 2012. Mesquite (*Prosopis* spp.) strategic plan 2012–17. Canberra: Weeds of National Significance, Australian Governmental Department of Agriculture, Fisheries and Forestry.
12. Balasubramaniam, V. 1991. Flora of Ramanathapuram district of Tamil Nadu. Bharathiyar University, PhD thesis. http://hdl.handle.net/10603/102745
13. Barba, P., Frias, J.T., Olalde, V. and Castaneda, J.G. 2006. Processing, nutritional evaluation and utilization of whole mesquite flour (*Prosopis laevigata*). *Food Science*, 71, S315- S320.
14. Basavaraja, P.K., Sharma, S.D., Badrinath, M.S., Sridhara, S. and Hareesh, G.R. 2007. *Prosopis juliflora* – An Efficient Tree species for Reclamation of salt affected soils. *Karnataka Journal of Agricultural Science*, 20, 727-731.
15. Bedunah, D.J. and Sosebee, R.E. 1986. Influence of mesquite control on soil erosion on a depleted range site. *Journal of Soil and Water Conservation*, 41, 131–135.
16. Boettcher, S.E. and Kalisz, P.J. 1989. Single-tree influence on soil properties in the mountains of eastern Kentucky. *Ecology*, 71, 1365-1372.
17. Bokrezion, H. 2008. The ecological and socio-economic role of *Prosopis juliflora* in Eritrea: an analytical assessment within the context of rural development in the Horn of Africa. PhD Thesis, Johannes Gutenberg University, Mainz.
18. Brown, J.R. and Archer, S. 1990. Water relations of a perennial grass and seedling vs. adult woody plants in a subtropical savanna, Texas. *Oikos*, 57, 366-374.
19. Brown, L.S., Boudjelas, S. and De Poorter, M. 2004. 100 of the world's worst invasive alien species: a selection from the global Invasive Species Database. Auckland, New Zealand: The Invasive Species Specialist Group (ISSG), Species Survival Commission (SSC) of the World Conservation Union (IUCN).
20. Burkart, A. 1976. A monograph of the genus *Prosopis* (Leguminosae sub fam. Mimosoideae). Part 1 and 2. Catalogue of the recognised species of *Prosopis*. *Journal of the Arnold Arboretum*, 57, 219–249, 450–526.
21. Cable, D.R. 1976. Twenty years of changes in grass production following mesquite Control and reseeding. *Journal of Range Management*, 29, 286-289.
22. Catterson, T. 2003. Strategic integrated plan in the Sudan, 2003-2005 environmental threats and opportunities assessment: *USAID/REDSO/NPC and the USAID Sudan Task Force*. Washington, March 2003.

23. Chandrasekaran, S., Sarawathy, K., Saravanan, S., Kamaladhasan, N. And Nagendran, N.A. 2014. Impact of *Prosopis juliflora* on nesting success of breeding wetland birds at Vettangudi Bird Sanctuary, South India. *Current Science*, 10, 676-678.
24. Chellamuthu, V., Balasusbramanian, T.N., Rajarajan, A. and Palaniappan, S.N. 1997. Allelopathic influence of *Prosopis juliflora* (Swartz) DC. on field crops. *Allelopathy Journal* 4, 291–302.
25. Chikuni, M.F., Dudley, C.O. and Sambo, E.Y. 2004. *Prosopis glandulosa* Torry (Leguminosae-Mimosoidae) at Swang'oma, Lake Chilwa plain: a blessing in disguise. *Malawi Journal of Science and Technology*, 7, 10–16.
26. Chinnimani, S. 1992. Silvipasture and natural grasslands of Mahi ravines and ravines of Gujarat. *Journal of Range Management and Agroforestry*, 13, 175-181.
27. Choge, S.K. and Ngujiri, F.D. 2006. Status impact of *Prosopis* species in Kenya. *In: Problems posed by the introduction of Prosopis spp. in the selected countries*. Plant Production and Protection Division, Food and Agriculture Organization of the United Nations, Rome. pp. 29-35.
28. Choge, S.K., Ngujiri, F.D., Kuria, M.N., Busaka, E.A and Muthondeki, J.K. 2002. The status and impact of *Prosopis* spp. in Kenya. Nairobi: KEFRI.
29. Choge, S.K., Ngunjiri, F.D., Kuria, M.N. Busaka, E.A. and Muthondeki, J. K. 2002. The status and impact of *Prosopis* spp. in Kenya. Technical report produced by the Kenya Forestry Research Institute and Forest Department. pp. 17–22, 94.
30. Choge, S.k., Pasiecnik, N.M., Harvey, M., Wright, J., Awan, S.Z. and Harris, P.J.C. (2007). *Prosopis* pods as human food, with special reference to Kenya. *Waters South Africa*, 33, 419-424.
31. Curtis, J.T. 1959. The Vegetation of Wisconsin. An ordination of plant communities, University Wisconsin press, Madison Wisconsin, pp. 657.
32. Curtis, J.T. and McIntosh, R.P. 1950. The interrelations of certain analytic and synthetic phyto sociological characters. *Ecology*, 31, 434-455.
33. DeLoach, C.J. 1984. Conflicts of interest over beneficial and undesirable aspects of *Prosopis* (*Prosopis* spp.) in the United States as related to biological control. Sixth International Symposium on Biological Control, Vancouver, Canada, 19–25 August, 301–340.
34. Djoudi, H., Brockhaus, M. and Locatelli, B. 2011. Once there was a lake: vulnerability to environmental changes in northern Mali. *Regional Environmental Change*, 11, 1–16.
35. Dzikiti, S., Schachtschneider, K., Naiken, V., Gush, M., Moses, G. and, Le Maitre, D.C. 2013. Water relations and the effects of clearing invasive *Prosopis* trees on groundwater in an arid environment in the Northern Cape, South Africa. *Journal of Arid Environments*, 90, 103–113.

36. Ehrenfeld, J.G., Kourtev, P. and Huang, W. 2001. Changes in soil functions following invasions of exotic under storey plants in deciduous forests. *Ecological Applications*, 11, 1287-300.
37. El Fadl, M.A. 1997. Management of *Prosopis juliflora* for use in agroforestry systems in the Sudan. *Tropical Forestry Reports* 16. University of Helsinki, Helsinki, Finland.
38. Elfadl, M.A. and Luukkanen, O. 2006. Field studies on ecological strategies of *Prosopis juliflora* in a dry land ecosystem. *Journal of Arid Environments*, 66, 1–15.
39. El-Keblawy, A. and Al-Rawai, A. 2006. Impacts of the invasive exotic *Prosopis juliflora* (Sw.) D.C. on the native flora and soils of the UAE, Biomedical and Life Sciences. *Plant Ecology*, 190, 23-35.
40. El-Sharkawi, H.M., Farghali, K.A. and Sayed, A.A. 1997. Tri factorial interactive effects of nutrients, water potential and temperature on carbohydrate allocation to the embryonic axis of desert plant seeds. *Journal of Arid Environments*, 35, 655-664.
41. FAO. 2006. Problems posed by the introduction of *Prosopis* spp. in selected countries. Rome: Plant Production and Protection Division, Food and Agricultural Organization of the United Nations.
42. Felker, P. 2005. Mesquite Flour: New Life for an Ancient Staple. Gastronomica: *The Journal of Food and Culture*, 5, 85-89.
43. Felker, P. 1979. Mesquite: an all-purpose leguminous arid land tree. In: Eitchie GA, ed. New agricultural crops, American Association for the Advancement of Science Symposium Proceedings, Vol. 38. Boulder: Westview Press, 89–132.
44. Felker, P., Cannell, G.H., Osborn, J.F., Clark, P.R. and Nash, P. 1983. Effects of irrigation on biomass production of 32 *Prosopis* (mesquite) accessions. *Experimental Agriculture*, 19, 187–198.
45. Finzi, A.C., van Breemen, N. and Canham, C.D. 1998. Canopy tree-soil interactions with in temperate forests: species effects on pH and cations. *Ecological Applications*, 8, 447-454.
46. Ganesh, P.S., Ramasamy, E.V. Gajalakshmi, S. and Abbasi, S.A. 2005. Extraction of volatile fatty acids (VFAs) from water hyacinth using inexpensive contraptions, and the use of the VFAs as feed supplement in conventional digesters. *Biochemical Engineering Journal*, 27, 17–23.
47. Geesing, D., Al-Khawlani, M. and Abba, M.L. 2004. Management of introduced *Prosopis* species: can economic exploitation control and invasive species? *Unasylva*, 217, 36–44.
48. Geesing, D., Al-Khawlani, M., and Abba, M.L. 2004. Management of introduced *Prosopis* species: can economic exploitation control an invasive species?. Unasylva, Vol.55, pp. 217.
49. Ghazanfar, S.A. 1996. Invasive *Prosopis* in Sultanate of Oman. *Aliens*, 3, 10.
50. Gibbens, R.P., Herbel, C.H., Morton, H.L., Lindeman, W.C., Ryderwhite, J.A., Richman, D.B., Huddleston, E.W., Conley, W.H., Davis, C.A., Reitzel, J.A., Anderson, D.M. and Guiao, A. 1986.

Some impacts of 2, 4, 5- T on a mesquite dune land Ecosystem in southern New Mexico. *Journal of Range Management*, 39, 320-326.

51. Goel, U., Saxena, D.B. and Kumar, B. 1989. Comparative study of allelopathy as exhibited by *Prosopis Juliflora* swartz and *Prosopis cineraria* (L) druce. *Journal of Chemical Ecology*, 15, 591–600.
52. Goel, V. and Behl, H.M. 1992. Wood quality for fuel wood rotation cycles. In: IUFRO Conference, 23-28 August 1992, Nancy, France.
53. Gutteridge, R.C. and Shelton, H.M. 1998. Pasture Tree Legumes in Tropical Agriculture. The a Tropical Grassland Society of Australia Inc.
54. Henry, A.N., Chithra, V. and Balakrishnan, N.P. 1989. Flora of Tamil Nadu, Series–I, Vol. 3. Botanical survey of India, Coimbatore.
55. Henry, A.N., Kumari, G.R. and Chithra, V.1987. Flora of Tamil Nadu, India. Series. 1, Vol. 2. Botanical Survey of India, Coimbatore.
56. Hibbard, K.A., Archer, S., Schimel, D.S. and Valentine, D.W. 2001. Biogeochemical changes accompanying woody plant encroachment in a subtropical savanna. *Ecology*, 82, 1999-2011.
57. Hunde, A. and Thulin, M. 1989. *Mimosoideae. In*: Hedberg I, Edwards S (eds), Flora of Ethiopia: *Pittosporaceae* to *Araliaceae*, Vol. 3. Addis Ababa University, Addis Ababa and Uppsala University, Sweden, pp. 71-98.
58. IPA (INTERNATIONAL *PROSOPIS* ASSOCIATION), 1989. IPA News 8:6. IPA, Recife, Brazil.
59. Johnson, N.C. and Wedin, D.A. 1997. Soil carbon, nutrients and mycorrhizae during conversion of dry tropical forest to grassland. *Ecological Applications*, 7, 171-182.
60. Kahi, C.H., Ngugi, R.K., Mureithi, S.M. and Ngethe, J.C. 2009. The canopy effects of *Prosopis juliflora* (dc.) and *Acacia tortilis* (hayne) trees on herbaceous plants species and soil physico-chemical properties in Njemps flats, Kenya. *Trop. Subtrop. Agroecosyst.*, 10, 441–449.
61. Kanzaria, M.K. and Varshney, A.K. 1998. *Prosopis juliflora* - its uses. . In: *Prosopis* Species in the Arid and Semi-Arid Zones of India (Eds. Tewari, J.C., Pasiecznik, N.M. Harsh, L.N. and Harris, P.J.C.), Proceedings of a conference held at the Central Arid Zone Research Institute, Jodhpur, Rajasthan, India on November 21-23, 1993. The *Prosopis* Society of India and the Henry Doubleday Research Association and CZARI, Jodhpur, India.
62. Kaur, R. and Callaway, R.M. 2014. Soils and the conditional allelopathic effects of a tropical invader. *Soil Biology and Biochemistry*, 78, 316–325.

63. Kaur, R., Gonzales, W.L., Llambi, L.D., Soriano, P.J., Callaway, R.M., Rout, M.E., Gallaher, J.T. and Inderjit. 2012. Community impacts of *Prosopis juliflora* invasion: biogeographic and congeneric comparisons. *PLoS One*, 7, e44966.
64. Kazmi, S.M.H. and Singh, R. 1992. Wood anatomy of exotics grown in India. 3. *Prosopis juliflora* (Sw.) DC. (Leguminosae). *Journal of the Timber Development Association of India*, 38, 39-42.
65. Kelly, E.F., Chadwick, O.A. and Hilinski, T. E. 1998. The effect of plants on mineral weathering. *Biogeochemistry,* 42, 139-143.
66. Khan, D., Ahmad, R. and Ismayil, S. 1986. Case History of Prosopis juliflora Plantation at Makran Coast through Saline Water Irrigation. Department of Botany, University of Karachi, Karachi, Pakistan, Proceeding of US-Pakistan Biosaline Research Workshop, Karachi, Pakistan.
67. Laxe´n, J. 2007. Is *Prosopis* a curse or a blessing? An ecological and economic analysis of an invasive alien tree species in Sudan. In: Lukkanan O, ed. Tropical forestry reports. Finland: VITRI, University of Helsinki, 1–199.
68. Le Maitre, D.C., Versfeld, D.B and Chapman, R.A. 2000. The impact of invading alien plants on surface water resources in South Africa: A preliminary assessment. *Water South Africa*, 26, 397-408.
69. Le Maitre, D.C., Versfeld, D.B. and Chapman, R.A. 2000. The impact of invading alien plants on surface water resources in South Africa: a preliminary assessment. *Water SA*, 26, 397–408.
70. Lima, P.C.F. 1994. Comportamento silvicultural de species de *Prosopis*, em Petrolina-PE, Região Semi-Arida Brasileira. PhD thesis, Universidade Federal do Parana, Brazil.
71. Low, T. 2012. In denial about dangerous aid. *Biological Invasions*, 14, 2235–2236.
72. Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M. and Bazzaz, F.A. 2000. Biotic invasions: causes, epidemiology, global consequences and control. *Ecological Applications,* 10, 689-710.
73. Magid, T.D.A. 2007. An Approach towards Mesquite Management in Kassala State. Ph.D thesis. University of Khartoum. Sudan.
74. Magurran, A. 1988. Ecological Diversity and its measurement. Taylor and Francis. pp.179.
75. Masakha, F.J. and Wegulo, F.N. 2015. Socioeconomic impacts of *Prosopis juliflora* on the People of Salabani Location, Marigat District, Baringo County in Kenya. *Journal of Natural Sciences Research*, 5, 41-46.
76. Matthew, K.M. 1995. An Excursion Flora of Central Tamil Nadu, India. Oxford & IBH Publishing: New Delhi.

77. McGinley. 2007. Effects of the biological invasion of algaroba: *P. juliflora* (Sw.) DC. on composition and structure of the shrub-tree stratum of the caatinga in Monteiro Municipality, Paraiba State, Brazil. *Biodiversity, Ecology and Environmental health,* 20, 887-898.
78. Milton, S.J., Dean, R.J and Richardson. 2003. Economic incentives for restoring natural capital in Southern African rangelands. *Frontiers in Ecology and the Environment,* 1**,** 247-254.
79. Mittermeier, R.A., Gil, P.R., Hoffman, M., Pilgrim, J., Brooks, T., Mittermeier, C.G., Lamoreux, J. and Da Fonseca, G.A.B. 2005. Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions. University of Chicago Press, Illinois, USA.
80. Mooney, H.A. and Cleland E.E. 2001. The evolutionary impact of invasive species. Proceedings of the National Academy of Sciences, 98, pp. 5446-5451.
81. Morgan, A.M.A., Hamdoun, A.M. and Bashir, N.H.H. 2017. Studies on seed germination and seedling emergence of Mesquite, *Prosopis juliflora* (Swartz) DC. In Sudan Gezira. *Universal Journal of agricultural research*, 5, 159-163.
82. Muthana, K.D. and Arora, G.D. 1983. *Prosopis juliflora* (Swartz) D.C., a fast growing tree to bloom the desert. CAZRI. Monograph No.22. Central Arid Zone Research Institute, Jodhpur, India. pp. 19.
83. Muturi, G.M., Mohren, G.M.J. and Kinani. J.N. 2009. Prediction of *Prosopis* species invasion in Kenya using geographical information system techniques. *African Journal of Ecology*, 48, 628–636.
84. Nair, N.C. and Henry, A.N. 1983. Flora of Tamilnadu, India Series 1: 13.
85. Nair, P.K.R. 1987. Soil productivity under agroforestry. In: Agroforesty: Realities, potentials and possibilities (Ed. Gholz.H), Martinus Nijhoff, The Hague. pp.21-30.
86. Nakano, H., Fujii, Y. Yamada, K. Kosemura, S. Yamamura, S. Hasegawa, K. and Suzuki, T. 2002. Isolation and identification of plant growth inhibitors as candidate (s) for allelopathic substance (s), from aqueous leachate from mesquite (*Prosopis juliflora* (Sw.) DC.) leaves. *Plant Growth Regulation*, 37, 113–117.
87. Nakano, H., Nakajima, E. Fujii, Y. Yamada, K. Shigemori, H. and Hasegawa, K. 2003. Leaching of the allelopathic substance,-tryptophan from the foliage of mesquite (*Prosopis juliflora* (Sw.) DC.) plants by water spraying. *Plant Growth Regulation*, 40, 49–52.
88. Nakano, H., Nakajima, E. Hiradate, S. Fujii, Y. Yamada, K. Shigemori, H. and Hasegawa, K. 2004. Growth inhibitory alkaloids from mesquite (*Prosopis juliflora* (Sw.) DC.) leaves. *Phytochemistry*, 65, 587–591.

89. Ndhlovu, T., Milton-Dean, S.J. and Esler, K.J. 2011. Impact of *Prosopis* (mesquite) invasion and clearing on the grazing capacity of semiarid Nama Karoo rangeland, South Africa. *African Journal of Range and Forage Science*, 28, 129–137.

90. Nie, W., Yuan, Y., Kepner, W., Erickson, C. and Jackson, M. 2012. Hydrological impacts of mesquite encroachment in the upper San Pedro watershed. *Journal of Arid Environments*, 82, 147–155.

91. Nilsen, E.T., Sharifi, M.R., Rundel, P.W., Jarrell, W.M. and Virginia, R.A. 1983. Diurnal and seasonal water relations of the desert phreatophyte *Prosopis glandulosa* (honey mesquite) in the Sonoran Desert of California. *Ecology*, 64, 1381–1393.

92. Noor, M., Salam, U. And Khan, M. A. 1995. Allelopathic effects of *Prosopis juliflora* Swartz, *Journal of Arid Environments*, 31, 83–90.

93. Noy-Meir I. 1973. Desert ecosystems: environment and producers, *Ann. laev. Ecology and Systematics J*, 25-51.

94. Pandey, C.N., Gandhi, B.L. and Kannoji, H.C. 1990. Kiln drying schedule for *Prosopis juliflora*. *Journal of the Indian Academy of Wood Science*, 21, 29-34.

95. Pandey, C.N. Gandhi, B.L. and Kannoji, H.C. 1990. Kiln drying schedule for *Prosopis juliflora. Journal of the Indian Academy of Wood Science*, 21, 29-34.

96. Pasiecznik, N.M. 1999. *Prosopis*-pest or providence, weed or wonder tree? *ETFRN News*, 28, 12–14.

97. Pasiecznik, N.M., Felker, P., Harris, P.J.C., Harsh, L.N., Cruz, J.C., Tewari, K., Cadoret and Maldonado, L.J. 2001. The *Prosopis juliflora, Prosopis pallida* Complex: A Monograph, The Forestry Research Programme. HDRA Conventry, UK. pp. 162.

98. Perroni-Ventura, Y., Montana, C. and, García-Oliva, F. 2010. Carbon–nitrogen interactions in fertility island soil from a tropical semi-arid ecosystem. *Funct. Ecol*., 24, 233–242.

99. Prasad, A.E. 2012. Landscape scale relationships between the exotic invasive shrub *Lantana camara* and native plants in a tropical deciduous forest in southern India. *Journal of Tropical Ecology*, 28, 55−64.

100. Raghubanshi, A.S., Rai, L.C., Gaue, J.P and Singh, J.S. (2005). Invasive alien species and Biodiversity in India. *Current Science*, 88, 1-12.

101. Raizada, M.B., and Chaerji R.N. 1954. "A diagnose key to the various forms of introduced mesquite (*Prosopis juliflora* DC)". *Indian Forester*, 80, 675-680.

102. Rajput, S.S. and Tewar, M.C. 1866. Some studies on the utilisation of bio-mass of *Prosopis* spp. pp. SSR1-SSR9. In: The Role of *Prosopis* in Wasteland Development. (Ed.) V. J. Patel. Javrajbhai Agro forestry Center, Surendrabag, Gujarat, India.

103. Ravindranath, N.H., and Sukumar, R. 1998. Climate change and tropical forests in India. *Climatic Change*, 39, 563−581.

104. Reddy, C.V.K. 1978. *Prosopis juliflora*, the precocious child of the plant world. *Indian Forester*, 104, 14-18.

105. Reddy, P.A., Kumaraguru, A., Bhagavatula, J., Gour, D.S., Bhavanishankar, M., Sarkar, M.S., Harika, K., Hussain, S.M. and Shivaji, S. 2012. Tiger presence in a hitherto unsurveyed jungle of India the Sathyamangalam forests. *Conservation Genetics*, 13, 779-787.

106. Reis, G., Lana, Â., Mauricio, R., Lana, R., Machado, R., Borges, I. and Neto, T. 2009. Influence of trees on soil nutrient pools in a silvopastoral system in the Brazilian Savannah. *Plant Soil*, 329, 185–193

107. Richardson, D.M and van Wilgen, B.W. 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts?. *South African Journal of Science*, 100, 45-52.

108. Richardson, D.M. 1998. Forestry trees as invasive aliens. *Conservation Biology*, 12, 18–26.

109. Riegelhaupt, E.I.B., Da Silva, F.B. Campello, and Pareyn, F. 1990. Volume, weight and product tables for *Prosopis juliflora* (Sw) DC at Rio Grande do Norte. pp. 69-91. In: The Current State of Knowledge on *Prosopis juliflora*. (Eds.) M. A. Habit and J. C. Saavedra. FAO, Rome, Italy.

110. Rodriguez-Iturbe, I. 2000. Ecohydrology: a hydrologic perspective of climate-soil vegetation dynamics, *Water Resour. Res*, 36, 3-9.

111. Ruijven, J.A., Gerlinde, B., Deyn, D. and Berendse, F. 2003. Diversity reduces invisibility in experimental plot communities: the role of plant species. *Ecology Letters*, 6, 910–918.

112. Ruthven, D.C. 2001. Herbaceous vegetation diversity and abundance beneath honey mesquite (*Prosopis glandulosa*) in the South Texas plains. *Texas Journal of Science,* 53, 171-186.

113. Sakthivadivel, R. 2016. *Prosopis juliflora* in the irrigation tanks of Tamil Nadu. *Water Policy Research Highlight*, 07, pp. 1-8.

114. Sanyal, S.N. and Saxena, R.C. 1980. Physical and mechanical properties of some Maharashtra timbers. *Journal of the National Buildings Organisation*, 15, 1-5.

115. Schade, J.D. and Hobbie, S.E. 2005. Spatial and temporal variation in islands of fertility in the Sonoran Desert. *Biogeochemistry*, 73, 541–553

116. Scifres, C.J. and Brock, J.H. 1970. Growth and development of honey mesquite seedlings in the field and greenhouse as related to time of planting, planting depth, soil temperature and top removal. Texas Agricultural Experiment Station, PR-2816, 65-71.

117. Sehar, A.C. and Rawat, N.S. 1960. A note on mechanical properties of *Prosopis juliflora*. *Indian Forester*, 86, 485-487.

118. Sen, D.N. and Sachwan, D.D. 1970. Ecology of desert plants and observation on Seedlings III. The influence of aqueous extracts of *P. juliflora* DC. on *Euphorbia caducifolia* Haines. *Vegetation,* 21, 277-298.

119. Shaik, G. and Mehar, S.K. 2015. Evaluating the allelopathic influence of mesquite (*Prosopis juliflora* DC.) aqueous leaf extract on the germination of rice (*Oryza sativa* L.) seeds using different germination indices. *International Journal of Pharma and Bio Sciences*, 6, B280–B287.

120. Sharma, R. 1993. An ecological assessment of the native *Prosopis cineraria* (L.) Druce and the alien *P. juliflora* (Sw.) DC. (Leguminosae Sub fam. Mimosoideae) Ph.D.thesis, University of Delhi, India.

121. Shiferaw, H., Teketay, D., Nemomissa, S. and Assefa, F. 2004. Some biological characteristics that foster the invasion of *Prosopis juliflora* (Sw.) DC. at Middle Awash Rift Valley Area, north-eastern Ethiopia. *Journal of Arid Environments*, 58, 135–154.

122. Shiferaw, H., Teketay, D., Nemomissa, S. and Assefa, F. 2004. Some biological characteristics that foster the invasion of *Prosopis juliflora* (Sw.) DC. at Middle Awash Rift Valley Area, northeastern Ethiopia. *Journal of Arid Environments*, 58, 134–153.

123. Shukla, N.K., Khanduri, A.K., Lal, K. and Lal, M. 1990. Physical and mechanical properties of some exotic species. Indian Forester, 116, 140-147.

124. Silva, A. (1986). Utilization of flour from *Prosopis juliflora* pods as a substitute for wheat flour in rations for egg-laying hens; The Current State of Knowledge on *Prosopis juliflora*; In: *International Conference* on *Prosopis*–Recife, Brazil, pp. 25–29.

125. Simmons, M.T., Archer, S.R., Ansely, R.J. and Teague, W.R. 2007. Grass effects on tree (*Prosopis glandulosa*) growth in a temperate savanna. *Journal of Arid Environment*, 69, 212-217.

126. Singh, G. 1998. Practices for raising *Prosopis* plantations in saline soils. In: *Prosopis* Species in the Arid and Semi-Arid Zones of India (Eds. Tewari, J.C., Pasiecznik, N.M. Harsh, L.N. and Harris, P.J.C.), Proceedings of a conference held at the Central Arid Zone Research Institute, Jodhpur, Rajasthan, India on November 21-23, 1993. The *Prosopis* Society of India and the Henry Doubleday Research Association and CZARI, Jodhpur, India.

127. Stark, J., Terasawa, K. and Ejigu, M. 2011. Climate change and conflict in pastoralist regions of Ethiopia: mounting challenges, emerging responses. CMM Discussion Paper No. 4. Washington, DC: United States Agency for International Development.

128. Suresh, H.S., Dattaraja, H.S. and Sukumar, R. 1996. The flora of Mudumalai wildlife sanctuary, Tamil Nadu, southern India. *Indian Forester*, 122, 507–519.

129. Tidemann, A.R. and Klemmedson, J.O. (1973). Effect of mesquite on physical and chemical properties of the soil. *Journal of Range Management*, 26, 27-29.

130. Tiwari, J.W.K. 1999. Exotic weed *Prosopis juliflora* in Gujarat and Rajasthan, India-boon or bane? *Tigerpaper*, 26, 21–25.

131. van Klinken, R.D., Graham, J. and Flack, L.K. 2006. Population ecology of hybrid mesquite (*Prosopis* species) in Western Australia: how does it differ from native range invasions and what are the implications for impacts and management? *Biological Invasions*, 8, 727–741.

132. van Wilgen, B., Reyers, W.B., Le Maitre., D.C., Richardson, D.M and Schonegevel, L. 2008. A biome-scale assessment of the impact of invasive alien plants on ecosystem services in South Africa. *Journal of Environmental Management.* 89, 336-349.

133. van Wilgen, B.W. and Richardson, D.M. 2014. Challenges and trade-offs in the management of invasive alien trees. *Biological Invasions*, 16, 721–734.

134. van Wilgen, B.W., Forsyth, G.G., Le Maitre, D.C., Wannenburgh, A., Kotze, D.F., van den Berg, E. And Henderson, L. 2012. An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa. *Biological Conservation*, 148, 28–38.

135. van Wilgen, B.W., Le Maitre, D.C. and Cowling, R.M. 1998. Ecosystem services, efficiency, sustainability and equity: South Africa's working for Water programme. *Trends in ecology and Evolution,* 13, 378.

136. Vitousek, P.M. and Walker, L.R. 1989. Biological invasion by *Myrica faya*. Hawai'i: plant demography, nitrogen-fixation and ecosystem effects. *Ecological Monographs*. 59, 247-265.

137. Wahome, R., Choge, S. and Pasiecznik, N. 2008. A global overview of the actual use of *Prosopis* pods as an animal feed and their potential value in Kenya. Linking industry to the *Prosopis* pod resource. Soi Safari Lodge, Baringo, Kenya, 12-13 March 2007. ILRI, Nairobi, Kenya.

138. Walter, K. 2011. *Prosopis*, an Alien among the Sacred Trees of South India. Doctoral dissertation (monograph), University of Helsinki, Faculty of Agriculture and Forestry, Department of Forest Sciences.

139. Wick, B. and Tiessen, H. 2008. Organic matter turnover in light fraction and whole soil under silvopastoral land use in semiarid northeast Brazil. *Rangeland Ecol. Manage.*, 61, 275-283.

140. Wilcove, D.S., Rothstein, D., Dubow, J., Philips, A. and Losos, E. 1998. Quantifying threats to imperilled species in the United States. *Bioscience,* 48, 607-615.

141. Wise, R.M., van Wilgen, B.W. and Le Maitre, D.C. 2012. Costs, benefits and management options for an invasive alien tree species: the case of mesquite in the Northern Cape, South Africa. *Journal of Arid Environments*, 84, 80-90.

142. Yadav, R., Yadav, B. and Chhipa, B. 2008. Litter dynamics and soil properties under different tree species in a semi-arid region of Rajasthan, India. *Agrofor. Syst*., 73, 1–12