REVIEW ARTICLE

Invasive *Prosopis juliflora*: Role in Maintaining the Ecosystem Resilience of the Banni Grassland in Arid Gujarat, India

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Abstract

Prosopis juliflora is one among the top hundred recognized invasive species worldwide. The synergized effect of arid climatic conditions and inherent soil salinity channeled this species's intentional introduction in Banni grassland. Due to the allelopathic effect of this species the existence of native grass species is in danger. However, in recent years, *P. juliflora* has replaced many of the native vegetation and is being recognized as an important species for the ecological stability of Banni grassland. Several ecologists have studied the role of this species in stabilizing the grassland ecosystem. In the present paper, its economic role is broadly reviewed with the vegetation cover maintained by it. In Banni grassland, the grass species grow only in monsoon and persists few months. For rest of the year (i.e. in summer) the green cover is maintained by *P. juliflora*. However, this species has provided remarkable livelihood opportunities. Apart from counting the negative effects, the counter-positive effects of the species have been recognized through this paper. *P. juliflora* has slowly transformed the Banni grassland into woodland. It has also altered the micro-diversity in the soil and ultimately transformed the whole ecosystem into new regimes. Eradication and reversion of *P. juliflora* spread is rather impossible. Hence, the management aspects of *P. juliflora* that need to maximize its positive features are discussed.

Keywords: Arid ecosystem, Banni grassland, Habitat transformation, Invasion management.

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Introduction

Prosopis juliflora (family: Fabaceae) has been described as one of the most troublesome invasive species world over because of its biological invasion in tropical, arid, and semi-arid areas. This species has led to biodiversity loss and changes in land use in numerous regions of the world. This plant is indigenous to the Caribbean, Central American, and North American regions and has a broad evergreen canopy with a height of about 14 m. One of its most distinctive traits is the ability to grow quickly and tolerate arid and semi-arid environments (Pasiecznik *et al.*, 2004). This mesquite plant grows thick, powerful roots that allow it to access subsurface water. This species is adapted for a wide range of extreme climatic conditions like extreme drought to flood, salinity etc. Its initial introduction was most successful because it grows in dense thickets, is tasty to livestock and herbivores, and performs well in terms of reproduction, yielding up to 40 kg

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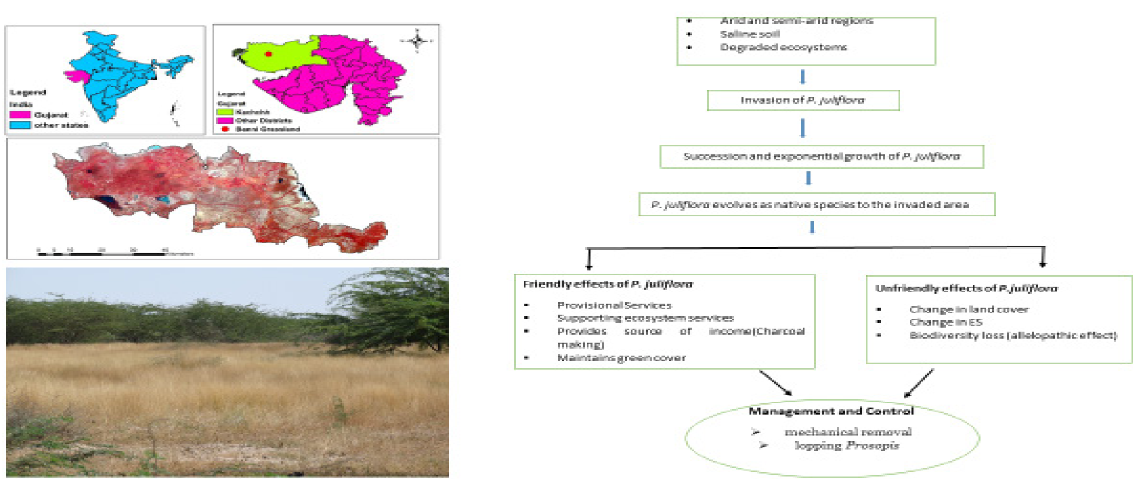

Fig. 1: Location and map of Banni grassland in Gujarat, India and overview of its invasion, importance, management and control

of seedpods and 60,000 seeds a year (Alban *et al.*, 2002). The seeds of *P. juliflora* have high seed viability and germinate fast in arid soil, ultimately imposing competition with native species. In degraded arid ecosystems *P. juliflora* was intentionally introduced to maximize the ecosystem services.

The *P. juliflora* is a stress tolerant species influencing ecosystem resilience. The capacity of a system to recover from the effects of static changes and other driving parameters is called Ecosystem resilience (Holling, 1973). It is assumed that managing the resilience of an ecosystem's attribute is not sufficient to evaluate the whole ecosystem. Developing future management plans that aim for a state of ecosystem resilience requires a thorough understanding of the intricate interplay between an ecosystem's resilience capacity and the factors affecting that capacity. This 'command and control' approach (Holling and Meffe *etal.*, 1996) supports amplifying selected managing features to produce maximum expected resources, simultaneously reducing the adaptation of other ecosystem components (Reyes and Kneeshaw, 2014).

A debate about the interaction between biodiversity and ecosystem resilience has been going on among researchers. Some researchers support a positive correlation between biodiversity and ecosystem resilience (Tilman, 1984; Baskin, 1994) while others contradict this and focus on the particular functions of species either as driver species and/or passenger species (Lepš *et al.*, 1982; Elmqvist *et al.*, 2003), where driver species influence the functioning of an ecosystem. Hence, the interactions between biodiversity and ecological resilience are a topic of controversy among scientists. Plant diversity has been positively correlated with the sustainability of the grassland ecosystem (Lehman and Tilman, 2000; Biondini, 2007). Grasslands with a large range of biodiversity are more stable to disturbances (Isbell *et al.*, 2015). However, biological invasion stimulates shifting mechanism of ecosystem characteristics and effects ecosystem resilience and threshold dynamics (Chaffin *et al.*, 2016).

Diagnosis of ecosystem resilience is a critical premise for ensuring the ecosystem's as well as the socioeconomic system's long-term growth. Ecosystem resilience is analyzed through the ecosystem services extracted from that particular system. In this paper we briefly discuss the role of *P. juliflora* in maintaining the ecosystem services in Banni grassland. The introduction of this species has both positive and negative ecological effects. These effects are reviewed to justify its advantageous and disadvantageous impacts in supporting life in Banni grassland (Fig. 1).

Shirke *et al.* (2018) explained this invasive species' potential to express maximum carbon fixation in monsoon season through physiological modifications in terms of enhanced photosynthetic activities supported by moderate temperature ranges. These authors stated that leaves of this plant grown in monsoon shows sensitivity towards low temperature and fall in winter whereas leaves grown in spring season are sensitive to high temperature.

Overview of *P. juliflora* as an Invasive Species

P. juliflora is one of the plant species cultivated to counter the effects of extreme climatic conditions and avoid land degradation. However, intrusion of this species in tropical grasslands, with the intention of grassland restoration, supports vital ecosystem services like climate change mitigation and maintains the area's sustainability. Linders *et al.* (2020), studied the effect of *Prosopis spp.* invasion through the assessment of ecosystem services and revealed a directly proportional relation between its density and woody biomass. Ecosystem services are the benefits gained by humans from the ecosystem. The introduction of *P. juliflora* in degraded ecosystems increases the benefits of ecosystem services for the local peoples. Plantation of *Prosopis juliflora* in semi-arid region in Baringo, Kenya increased the carbon stocks in soil (mostly in upper 30 cm depth) at a rate of 1.4% per year but kept control on biodiversity and herbaceous biomass (Mbaabu *et al.*, 2020). These authors also recorded an increased production of fodder and wood in *Prosopis*-invaded areas. Zarzosa *et al.*, (2021), focused on the adaptability of this species in drylands, including its industrial utilization. The leaf litter produced under the micro-environment of the canopy enhances the microbial activity that simultaneously increases the productivity of soil (Salazar *et al.*, 2019a, 2019b). Further, phytoremediation properties of *P. juliflora* have also been recorded for heavy metals in industrial areas (Senthilkumar *et al.*, 2005).

However, high *Prosopis* density has also been reported to negatively affect herbaceous biomass. Linders *et al.* (2020) reported its negative effects on livestock and income from cattle rearing while Dzikiti *et al.* (2013) reported negative effects on other ecosystem services like grassland pastures and groundwater availability. Additionally, an increase in human disease vectors due to invasion of *Prosopis*, impacting ecosystem services has also been reported (Muller *et al.*, 2017). Thus, researchers have published both the positive and negative aspects of *Prosopis* spp. invasion on rural livelihoods in terms of livelihood vulnerability.

Edaphic characteristics like soil alkalinity, clay fractions, and the mean temperature of the driest quarter of the year, all enhance the possible invasion of *P. juliflora*. The risk of invasion is greatest for arid and semi-arid lands compared to other moist biomes (Dakhil *et al.*, 2021). The rate of its invasion is sped up by the plants' capacity to adapt to a wide range of climatic and soil conditions, strong coppicing ability, efficient dispersal mechanisms, and production of allele chemicals. Additionally, this species reproduces sexually by producing a significant number of viable seeds and asexually by adventitious buds formed on the shallow roots. Furthermore, the latent seeds form robust seed banks during unfavorable years of below-average precipitation or drought (Shiferaw and Demissew, 2023). Because of the wide variety of propagation techniques, *P. juliflora* has been able to effectively colonize new places.

Worldwide Introduction of *P. juliflora*

Since 2009, IUCN rated this species as one of the hundred most invasive alien species globally. This native species from parts of Central and north-western South America represents thorny scrublands (Kaur *et al.*, 2012) and has been introduced to many countries (Shackleton *et al.*, 2014) either intentionally or accidentally. It has conquered most of the regions in countries like Saharan southern Africa, Australia, the Middle East, Pakistan, Hawaii, and many states of India (Goslee *et al.*, 2003; Pasiecznik *et al.*, 2004). Reddy (2008) listed 173 invasive alien plant species in India, which included *Prosopis juliflora*. Different authors claim the introduction of this invasive alien species in Indian regions differently. As per Reddy (1978), the species was initially introduced in 1877 in the Cuddapah district of Andhra Pradesh while Rawat *et al.* (1992) reported it first introduced in 1875 in Punjab, and Gupta and Blara (1972) reported it to be in 1857 from Mexico. Though it was introduced in Gujarat around 1940, in Banni *P. juliflora* was introduced in the 1960s to check the salinity intrusion towards the grassland from the Great Rann of Kachchh (Kumar *et al.*, 2015). Reports published by FAO (1998) has highlighted the dense distribution of the species in arid and semi-arid regions of Gujarat, Rajasthan, Uttar Pradesh, Haryana, Maharashtra, Karnataka, Tamil Nadu, and Andhra Pradesh.

Intentionally, *Prosopis* sp. was introduced in many countries to meet various socio-economic and other needs like fodder for livestock, afforestation in arid regions, sand dune counterbalance, provision of firewood, reintegrating old quarries, bulwarking, soil reclamation, etc. In Baringo County, the Kenyan government promoted its introduction to support the livelihoods of local people (Mwangi and Swallow, 2008). It was expected that the establishment of this species would increase the organic carbon content in soils (Moradi *et al.*, 2017), thereby being considered a climate change mitigation measure and land degradation management practice.

As intra-species competition increases in dense vegetation, *Prosopis* takes a long time to sustain its invasive potential (Shackleton *et al.*, 2014). However, in open land, it invades very fast. Its introduction is correlated to its succession in ecosystems with climatic-driven factors that experience the degradation of a few ecosystem attributes. When native biodiversity of an ecosystem gets disturbed it is likely to give space to such invasive species. These species inhabit the new environment and become integral to the system. The ecosystem services, functionality, and composition adjust according to the new evolving ecosystem. Many researchers have highlighted that when any disturbance in an ecosystem attains a threshold value, the ecosystem disintegrates and, in some cases, the disturbed ecosystem is redirected to a reframed ecosystem to attain stability (Poorter *et al.*, 2016).

Impacts of *Prosopis Juliflora*

Health and Medicinal Benefits of P. juliflora

This mesquite plant is a rich source of biopharmaceutical chemicals that express high nutritional, antibacterial, antifungal, anti-inflammatory, anti-ulcer, and anti-emetic activities. Initially, Astudillo *et al.* (2000), highlighted high nutritional values of *Prosopis spp.* Later its antibacterial activity against *S. aureus* and *E. coli* was reported (Sukirtha and Growther, 2012) while the same activity was reported for ethanolic leaf and root extracts against gram-negative bacteria (Odhiambo *et al.*, 2015). Its aqueous extract is used in treating diseases caused by *Agrobacterium rhizogenes* and *Xanthomonas campestres* in plants (Sheikh *et al.*, 2012). Alkaloid and aqueous extracts (with compounds like zerumbone and cassine) of its leaves express remarkable antifungal activities, especially against *A. niger* (Napar *et al.*, 2012) and *A. fumigatus* (Sheikh *et al.*, 2012), respectively. Methanol extracts and petroleum-ether extracts of the leaves have anti-plasmodial activity (against *Plasmodium falciparum* and *Trypanosoma cruzi*) (Al-Musayeib *et al.*, 2012) and have been shown to resist the activities of harmful amoeba and other protists (Garbi*et al.*, 2014) respectively. Hasan *et al.* (2012) in a comparative study of various plant species for their anti-emetic activities, reported *P. juliflora*, to have the highest anti-emetic potential. The leaves of *P. juliflora* when extracted with ethanol (Choudhary and Nagori, 2013) revealed anti-inflammatory properties. Further, Wagh and Jain (2018) studied the ethnobotanical benefits of *P. juliflora* and reported using stem barks to treat asthma. Thus, medicines prepared from leaves, flowers, stem, and bark of *P. juliflora* are used for the treatment of pain, as body tonic, to treat boils, eye inflammation, kidney stones, toothache, breast cancer, cough, etc. (Umair *et al.*, 2017; Younis *et al.*, 2018).

Competition with Native Vegetation Due to Allelopathic Effects

Although the invasion of this mesquite species is bountiful in providing some requirements of the local people in the grassland, there are a few negative impacts that degrade the grassland's ecosystem services. When the leaves of *P. juliflora* fall on the ground, they release some inhibitors which inhibit the germination and growth of native vegetation and simultaneously changing the biodiversity (Getachew *et al.*, 2012). Numerous allelochemicals are thought to be produced by the plant's roots, stems, leaves, flowers, as well seeds, which are observed to reduce seed germination and also decrease growth and biomass production (Chellamuthu *et al.*, 1997; Shackleton *et al.*, 2015; Al-Abdali *et al.*, 2019). The allelopathy was linked to phenolic chemicals found in *P. juliflora* by these authors who investigated the impact of *P. juliflora* leaf litter.

Due to allelopathic effects, *P. juliflora* displaces adjacent plants and native species, endangering the floral biodiversity. It competes with native plant species by preventing seed germination and limiting the growth of their seedlings, which slows down the germination of seeds from other species. According to Abbasi and Abbasi (2011), the foliage of *P. juliflora* may contain water-soluble allelochemicals that are washed to the ground through rainwater leaching. These allelochemicals have been identified as syringin, (-)-lariciresinol, L-tryptophan, juliprosopine, juliprosine, and juliprosopinal by Nakano *et al.* (2002, 2003, 2004). The *Prosopis* invasion significantly impacted the variety of the soil seed bank. The results showed that, compared to *Prosopis* thickets, *Prosopis* + native species stands, and open grazing areas, the mean values of the Shannon diversity of non-invaded woods were greater by 19.2%, 18.5%, and 11.0%, respectively (Shiferaw *et al.*,2019).

Groundwater and Effect on Native Species

In India *P. juliflora* blooms twice a year viz. February–March and August–September. Grazing ungulates and livestock can easily access the pods when other vegetation is scarce, dispersing them with their droppings, which then germinate with the ensuing monsoon rains (Kumar and Mathur. 2014). This invasive plant has deep root system that can reach up to 15 metres below the surface and drain groundwater during both the rainy and dry seasons, with heightens the groundwater withdrawal during dry season (Dzikiti *et al.*, 2013), a condition that is a threat for various grass species and major keystone plant species of the ecosystem (Veldman *et al.*, 2015a; 2015b). Such condition considerably worsens during local water shortages and also limits the water to other vegetation (Shiferaw *et al.*, 2021). This evergreen plant absorbs more water in the dry season than in the wet season. A *Prosopis* tree's daily average transpiration was around 3.4 (± 0.5) mm. The amount of water used by *P. juliflora* in the Afar Region was calculated using a fractional cover map of the plant (covering an area of 1.18 million hectares). The area's two primary crops, cotton and sugar cane, would be able to be irrigated with this amount of water, yielding projected net benefits of between US$320 million and US$470 million every growing season (Shiferaw *et al.*, 2021). Therefore, *P. juliflora* has negative effects on sustainable livelihoods in the area unless its spread is controlled and its density in regions where it has already established itself is decreased. The predicted net benefit would substantially justify A coordinated control program. However, Vallejo *et al.* (2012) have considered *Prosopis* as a fertility island tree that significantly increase soil nutrient concentration under its canopy, and improves soil microbial activity and diversity.

Effect on Ecosystem Processes and Services

Prosopis was intentionally cultivated to meet local communities' basic provisional services (firewood, charcoal, fodder, etc.). It is important to understand different variables of ecosystem services that improve the continuity of these services and maintain resilience (the capacity to endure and bounce back from disruption or alteration of the environment) (Carpenter *et al.*, 2001). The interdependence of ecosystem services on its biotic community composition has been explained (Kremen 2005; Bennett *et al.*, 2009; Luck *et al.*, 2009). According to Wei *et al.* (2017), the pressure on social-ecological systems can be identified through an assessment on the relationship between the supply, use, and demand of ecosystem services.

Ayanu *et al.* (2015) studied different types of ecosystem services provided by *P. juliflora* such as provisional (fodder and grass, fuel wood, charcoal, and water), regulatory services (erosion control, flood control, and soil salinity control) and cultural services as well. The provision of firewood and charcoal helps partially counter this invasion's detrimental effects. However, the challenges in stopping its rapid growth suggest that the risks it poses to ecosystem services, people's livelihoods, and lifestyles may outweigh its advantages (Ayanu *et al.*, 2015). Plantations of this invasive plant control soil erosion due to wind and soil moisture evaporation, thus maintaining soil moisture (Patnaik *et al.*, 2017). High *Prosopis* cover, with increased woody biomass and decreased herbaceous biomass, impacts the ecosystem services. The availability of woody biomass was strongly correlated with revenue from the sale of wood. In earlier days *Prosopis* invasion has been shown to cut livestock income through a marginal decrease in cattle population. However, within 10 years Nutrient values of soil (SOC, TN, TP, TS, and total soluble salts) have been shown to increase in a depth of 45 cm under *P. juliflora* canopy as compared to open land (Sadeq *et al.*, 2020).The ecosystem services provided by *P. juliflora* vary in different regions. In Afar rangelands (Ethiopia), introducing this invasive species has converted the grassland habitats into *P. juliflora* thickets and thus created a shortage of fodder for pastoralists (Berhanu and Tesfaye., 2006). But, in Banni grassland (Gujarat, India) this invasive plant is a good source of fodder for livestock (Kumar *et al.*, 2015). Mwangi and Swallow (2008) highlighted the beneficial effects of *P. juliflora* for improving soil health through the nitrogen cycle and has mitigated the application of commercial fertilizers. These attributes relate much more closely to the regulating and supporting functions of the ecosystem of *P. juliflora*. Nevertheless, Tebboth *et al.* (2020) have highlighted the contradiction between ecosystem services and disservices extracted from this invasive alien plant have pretended and proposed effective outcomes of the ecosystem. Utilization of these services by various social groups is influenced by their means of subsistence, resource needs, and resource availability. As a result, the advantages and disadvantages of *P. juliflora* tend to differ amongst the main user groups, including sedentary small-scale agro-pastoralists, mobile pastoralists, and large-scale farmers (Ayanu *et al.*, 2015). The invasion of *Prosopis* has caused changes in LULC patterns and the relevant Ecosystem Service Values have got depleted (Shiferaw *et al.*, 2019).

Changes in Soil Properties

The invasion of *Prosopis* has shown to influence the properties of soil in different ways in different areas. It has been reported to increase pH of soil and lower the exchangeable Na+ percentage (21.6%), as well as water-soluble Ca^{2+} and Mg^{2+} and these soils have 19% higher clay content as compared to non-invaded areas, which had (5.6%) higher sand content (Shiferaw *et al.*, 2021). Shiferaw *et al.* (2021) further described the increase in leaf litter mycorrhizal connections and/or nutrient addition into the soil under the canopy of *Prosopis*, with high levels of macro and trace elements. However, Shitanda *et al.* (2013) reported greater moisture content with slightly lower pH values in the soils of *Prosopis*-invaded land. Sadeq *et al.* (2020), reported low soil organic matter in topsoil, collected from both the understory and the adjacent areas. *P. juliflora* is also reported to maintain soil quality by assimilating pollutants and heavy metals and improving the soil binding capacity (Usha *et al.*, 2009). As said earlier *P. juliflora* was introduced in the Banni grassland to stop salt intrusion, control desertification and help in the prevention of soil erosion.

Litter from *P. juliflora* supports microbial activity and nutrient cycling (Salazar *et al.*, 2019a), through the symbiotic association of nitrogen-fixing microorganisms, simultaneously creating a micro fertility zone under its canopy (Abril *et al.*, 2009). Mehadi *et al.* (2019) documented that the introduction of *P. juliflora* supports soil microbial biomass of carbon and soil metabolic quotient of soil. This species also develops a physical barrier protecting the barren soil against environmental degradation (Okin and Gillette, 2001) while microclimatic conditions (Temperature, soil moisture) under the canopy is favourable for supporting life (Berry *et al.*, 2013).

Effects on Wildlife

Introduction of *P. juliflora* in an ecosystem degrades its integrity, thus increasing a risk for several wild animals. In dense mesquite, more black-tailed jackrabbits (*Lepus californicus*), antelope jackrabbits (*Lepus auema*) and Gambel's quail (*Lophora gambelia*) were observed than in mesquite-free regions (Germano *et al.*, 1983). These authors also reported increased bird population in the mesquite-covered range than regions with less or no mesquite. However, Misher and Vanak (2021) discovered that the desert fox prefers more open *Suaeda* dominating saline habitats as compared to *Prosopis* dominated habitats. A negative correlation between *P. juliflora* density and the bird diversity has been also been reported through a study on the relationship between tree species and avifaunal diversity (Khera *et al.*, 2009). While, comparing nesting success of birds on *P. juliflora* and *A. nilotica* in the Vettangudi Bird Sanctuary, Chandrasekaran *et al.*((2014) recorded higher number of fallen eggs and chicks under *P. juliflora* while higher number of fledglings per nest on *A. nilotica* relating the difference to the plant architecture. Koladiya *et al.* (2014) reported that sparsely distributed *Prosopis* habitat was the most diverse habitat for bird species whereas *Prosopis*-Capparis was the least diverse habitat for bird species. Further, Koladiya *et al.* (2016) recorded a total of 262 species of birds from the grassland. Not only birds but even butterfly showed avoidance of *Prosopis* invaded regions with low abundance and low density when compared to native vegetation where diverse food is available (Choudhary and Chishty, 2020).

Banni Grassland

The Habitat

Banni grassland (23°190 to 23°520 N latitude and 68°560 to 70°320 E longitude) is a mosaic of saline deserts, seasonal wetlands and savannah grassland ecosystems covering an area of 2675 km^2 in the central part of Kachchh District, Gujarat State, India (Fig. 1) (Mehta *et al.*, 2014). The eastern part of the grassland is part of the Kachchh Desert Wildlife Sanctuary and some western part of the grassland falls under Chhari Dhandh Conservation Reserve. The sparse vegetation of Banni mainly depends on monsoonal rainfall and soil salinity gradients. Grasses form the dominant vegetation of this ecosystem which starts germinating on the onset of monsoon in month of June-July and start drying by February-March (Figs 2, and 3). As Banni experiences inherent salinity, most of the vegetation comprises of halophytes and dominated by forbs, graminoids, and scattered thorny shrubs, while tree cover is maintained by the presence of *Salvadora oleoides, S. persica* and *P. juliflora* (Joshi and Kiran 2021). *P. juliflora* was intentionally introduced in Banni to check the spread of desertification in the grassland from the fringe areas of Great Rann of Kachchh lying on the northern part of the grassland (Kumar *et al.*, 2015). During the period of princely state, grazing in the grassland was managed and controlled by imposing fee but later the practice was abolished and hence livestock from other parts of the Gujarat state are also allowed to graze in the grassland. Due to the shortage of grasses during low rainfall or drought, most of the livestock migrate to other parts of the state for grazing (Bharara, 1987; Ferroukhi, 1994). Introduction and later invasion of *P. juliflora* and the simultaneous increase in the number of livestock in the region has crossed the limits of the carrying capacity of Banni ecosystem (Kumar *et al.*, 2015; Joshi and Kiran 2021). In Banni, native grass species are found only during the favorable season mainly monsoon and post-monsoon, while *P. juliflora*, the invasive alien species, has become a versatile and evergreen species.

Introduction of P. juliflora in Banni grassland

In 1961, the Forest Department, Government of Gujarat State, India, permitted the plantation of *P. juliflora* along the borderline separating Banni grassland and the Great Rann of Kutch (covering an area of 31,550 hectares) to check the spreading of salt marsh (Bharwada and Mahajan, 2012). After being introduced ten years prior, *P. juliflora* had already taken over about 20% of the Banni grassland by 1979. After that, *P. juliflora*'s dense cover continued to grow at an average pace of 2,670 ha/year during the second decade (Jadhav *et al.*, 1992) before progressively slowing down

Table 1: List of Research articles on *Prosopis* in Banni grassland

Year	*Author*	*Findings*
2022	Tundia *et al.* (2022)	Roots of *Prosopis juliflora* penetrate deep to consume underground water from deeper soils, leading to a shortage of water in Banni grassland.
2021	Kumar *et al.* (2021)	Coal making from *P. juliflora* has become a major occupation for locals in Banni area.
2021	Nerlekar *et al.* (2022)	Due to rapid growth of *P. juliflora* mechanical removal of *Prosopis* is initial step for grassland restoration.
2021	Joshi and Kiran (2021)	Net Ecosystem (CO_2) Exchange (NEE) value is much higher for grass spp. as compared to *P. juliflora* and *Acacia spp.*
2020	Sharma and Kumar (2020)	Salinity, vegetation, and moisture content of soil acts cumulatively for nitrogen transformation in Banni. Coal production shares a major fraction of annual income for Banni residents.
2018	Hiremath *et al.* (2018)	Due to ecosystem degradation caused by invasion of *P. juliflora*, local pastoralists are obliged to consider *P. juliflora* as fodderto compensate the loss of natural grassland ecosystem.
2018	Mathur and Sharma (2018)	According to PRP scenario, Banni will be able to restore and boost future incomes' present values by 62% by 2030. If the removal of *P. juliflora* is delayed for five years, there could be a deduction of 28% from the earnings.
2018	Dayal *et al.* (2018)	Restoration of grassland through controlled overgrazing practices is a measure to check the invasion of *P. juliflora*
2014	Pasha *et al.* (2014)	*P. juliflora* cover has increased by 2.1% from 2005 to 2011.
2012	Vaibhav *et al.* (2012)	Have measured biomass of *P. juliflora* in terms of carbon stocks as primary productivity.

Fig. 2: Banni grassland-Pre monsoon

Fig. 3: Banni grassland-Post monsoon

to 1,664 ha/year by the fourth until it was covering 30.7% of Banni densely and another 24% sparsely in 2009 (Safriel and Kumar, 2021). *Prosopis* dominating area in the Banni grassland has considerably increased from 6% in 1997 to 27.5% in 2008 (Shah and Somusundaram, 2010). *P. juliflora* colonized 55% of Banni forty years after its introduction (from 1960 to 1970) ended, converting substantial amounts of grassland to woods (GUIDE, 2011). Safriel and Kumar (2021) has highlighted that the loss of grassland cover in Banni may be almost evenly attributable to growing salinity and to *P. juliflora*'s competitive exclusion over the last decade of the 20th century and the first decade of the 21st century. During summer, when the grasses are not available for fodder, livestock feed on *P. juliflora* and spread its seeds through faecal matter (Kumar *et al*., 2015). For the stakeholders, plant diversity and richness changes have affected management and policy initiatives, and increased challenges to monitor changes through the frequent collection of field samples. Several studies have been conducted related to the Banni grassland which discusses the role of *Prosopis* in water availability, Coal making, rapid growth and related problems, comparison of ecological role with grasses, etc. Various authors working on various aspects on the *P. juliflora* and relationship with the ecology of the grassland is given in Table 1.

The Economic Impacts of *P. juliflora* in Banni

Livelihood opportunities

Climatic and anthropogenic causes threaten the grasslands world over. Banni grasslands is no exception where grass cover has declined, leading to decreased productivity from 4,000 kg per hectare in the 1960s to 620 kg per hectare in 1999 (Bharwada and Mahajan, 2012). The low precipitation and high temperatures with a synergized effect of inherent salinity are advantageous for the proliferation of *P. juliflora* in Banni. However, this evergreen and drought-tolerant plant has benefited the local society economically over the years. The introduction of *P. juliflora* has slowly naturalized and has become an integral part of the Banni ecosystem and started supporting provisional services (fodder, gum, wood for fuel, and charcoal production) with Charcoal making as a secondary income source for local peoples, for which *P. juliflora* wood is harvested (Mathur and Sharma 2018).

Effects on livestock production

Livestock related activities are the primary economic activities for agro-pastoral households in Banni. According to Bharwada and Mahajan (2012) population of Kankrej cattle declined due to the consumption of *P. juliflora* pods but later Kankrej cattle became adapted to the species and its population increased in *Prosopis* dense areas experiencing higher economic values. It is interesting to note that the families with more livestock preferred invasion of *Prosopis* in their agro-pastoral area as they could find alternative sources of income compared to those without agro-pastoral areas, as a result experiencing increased livestock production (Zeray *et al.*, 2017). However, close attention is required for managing herds (stocking and restocking) and using better feed and fodders, including *Prosopis* as a feed source.

Though it has been reported that there is improvement in livestock quality, some reports indicate exactly opposite. *Prosopis* invasion in agricultural fields has been reported to increase the market cost of crop produced due to the increased cost of eradicating it from the fields. Further, the invasion of *Prosopis* in grasslands or pasturelands reduces the native forage resources (Shackleton *et al.*, 2015), slowly converting the grassland into *Prosopis*-dominated woodlands. The nutritional values of the grassland is altered for livestock as grazing animals get very limited choice of plant species as fodder, in turn affecting the productivity of milk and meat. When the scarcity of grass species becomes severe, livestock are compelled to travel long distances in search of fodder. Such traveling across territories causes conflict among the native tribes and migrants. Degradation of grassland productivity has increased the market demand for fodder for the pastoral communities (Maldharis) which imposes an economic loss for the locals (Mathur and Sharma, 2018).

Costs of Management and Control

A decade ago it was thought that to minimize the negative effects of invasive species and optimize their positive effects, understanding its dynamics is crucial; yet, a framework and management policy for the invasive species was lacking (Wilson *et al.*, 2014). Chemical, mechanical, and biological methods have been used to reverse the invasion of *P. juliflora*. In chemical treatment, herbicides are applied on juvenile plants, and mechanical removal is done manually. Biological removal entails the controlled introduction of one or more alien species from the native regions of invasive plant species and is physiologically manipulated to compete exclusively with those plants of the same species. Assessing patterns of the spread of an invasive species to new locations is one of the most cost-effective ways to monitor and manage natural ecosystems because eradication efforts after the establishment of an alien invasive species are expensive and time-consuming (Heshmati *et al.,* 2019). Due to a lack of knowledge about factors affecting the invasion of the invasive species, management of the invaded species is ineffective in many regions. Understanding the benefits, costs, ecology, and sizes of incursions is crucial for the effective management of *P. juliflora* (Shackleton *et al.*, 2014; Wilson *et al.*, 2014). The best management approach facilitates maximizing the positive effects due to *P. juliflora* invasion (Wakie *et al.*, 2016). In Banni grassland, two methods of *Prosopis* removal (management) were practiced – mechanical removal and lopping. While cutting *Prosopis* close to the ground is how the local communities use it to make charcoal, mechanical removal mimics a strategy designed expressly for recovering grasslands (Ghosh, 2021). The best management methods involve the use as fuel wood, building materials and, making charcoal, and feeding livestock by crushing the pods. Banni is a large area, so chemical and mechanical removal are labor-intensive and expensive.

Conclusion

However, *Prosopis* was introduced to boost the ecosystem resilience potential of Banni grassland towards the extreme climatic conditions, with the pace of time *P. juliflora* became an integral part of Banni grassland. The soil microbial communities in the invaded areas is impacted by the allelochemicals released has limited the biodiversity in Banni grassland. Although the species provides a wide range of ecosystem services and has proved as the most valuable species for maintaining the green cover. In conclusion we can say that *P. juliflora* conserves the ecosystem resilience capacity of Banni grassland through continuous channelization of ecosystem services. Its invasion is now highlighted as a variable affecting the economy of locals. This phase of interaction between *P. juliflora* and ecosystem factors of Banni grassland marks a period of evolution, evolved from an invader species to a species that maintains the ecosystem resilience.

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Contribution of Authors

All authors provided critical feedback and helped shape the research, analysis and manuscript. Asha Sharma has written the manuscript with support and comments from Dr. Anand Kumar and Naorem while Prof. Geeta Padate has critically evaluated and edited the manuscript and contributed to the final version of the manuscript.

Conflict of Interest

All co-authors certify that the submission is original work and agree with the contents of the manuscript. We declare that there is no conflict of interest to report.

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