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Chapter

Effects of the Invasive Alien *Prosopis juliflora* (Sw.) DC and Its Management Options in Ethiopia: A Review

Wakshum Shiferaw and Sebsebe Demissew

Abstract

This paper aimed to review the effects of *P. juliflora* (hereafter *P. juliflora* is represented by *P. juliflora*) on environmental factors in Ethiopia, management options and take up lessons learned elsewhere, and discuss about utilization and management of *P. juliflora*. It addresses relevant scientific information based on the evaluation of data collected from different journals, books, manuals, and various reports using the systematic review method. Invasion of *P. juliflora* had positive effects on soil properties, negative effects on plant diversity, human health, livestock health, and other economic losses. Its negative effects are outweighing its positive effects. The main negative effects of *P. juliflora* are its biotic factors such as allopathic chemicals and active ingredients such as phenolic compounds that are impairing animals and human beings. Mechanical, chemical, management by utilization, fire, disruption of its phenological stages, and biological control methods are among control methods of the species. However, these control methods have their pros and cons for its management. The review was based on limited research findings and sources because there are limitations in research works regarding *P. juliflora* and its management. This review is used to know the invasion of *P. juliflora* and its management options in Ethiopia and other similar tropical countries across the world.

Keywords: allopathic, control methods, management, *Prosopis juliflora*, policy

1. Introduction

Invasive species are either indigenous or exotic which are being taken over a particular habitat [1, 2]. Invasive alien species are species that are introduced intentionally or unintentionally into new areas and cause loss on an environment they invade [2]. In recent decades, biological invasions are increasing [3, 4] and threaten ecosystems, biodiversity, and food security [5]. Invasive alien species are representatives of all taxonomic levels of viruses, bacteria, algae, plants, invertebrates, and large mammals [6].

In the world database, *P. juliflora* is one of the 100 worst invasive alien species [7]. The report by Ethiopian Biodiversity Institute showed 35 invasive alien plant species (IAPS) in the country [8]. Some of these invasive alien plants include *P. juliflora*, *Parthenium hysterophorus*, *Eichhornia crassipes*, *Lantana camara*, *Acacia drepanolobium*, *Orobanche,* and *Cuscuta* species, which are identified as major plant invaders [2]. It was found that there were emerging plant invaders such as *Cryptostegia grandiflora*, *Parkinsonia aculeate*, *Mimosa diplorotricha*, *Mimosa pigra*, and *Argemone Mexicana,* and *Nicotine glauca* [8]. In Ethiopia, plant species including *P. juliflora*, *P. hysterophorus*, *E. crassipes*, *L. camara,* and *A. drepanolobium* are the worst that threatened biodiversity losses [9]. These species were overtaking other land uses such as woodlands, grazing lands, parklands, urban greening, farmlands, which had reduced their ecosystem services of the land uses.

P. juliflora is a perennial evergreen multipurpose tree or shrub native to the Caribbean, North and South America transported out of its ranges through human activities [10–12]. It was introduced to African countries, for instance, since 1822 in Senegal, South Africa in 1880, Egypt in 1900, Kenya since 1973, and into Eritrea from Sudan probably during the early 1980s [2]. There is contradicting information regarding the introduction of *P. juliflora* into Ethiopia. For example, it was introduced in the late 1970s from India into Goro nursery-Dire-Dawa. On the other hand, *P. juliflora* was first introduced to the Afar region in the late 1970s. The introduction of *P. juliflora* in the Afar region was through coordinated efforts between government and communities to stop desertification, greening up the region, and mitigate the impacts of drought [12]. *P. juliflora* was then planted over large areas up to 1982, and the sector Food for Work Program in 1986–1988 continued to expand its plantation. This species now exists in most regions of Ethiopia for instance, Afar, Oromia, Amhara, Somali, and Southern Nations and Nationalities Region States. It was reported as one of the invasive and problematic invasive alien species in Afar and Somali Regions and expanded to Great Rift Valley toward South Omo in Southern Nations and Nationalities Regional State of Ethiopia [13] and is the dominant invasive tree species in semiarid and arid ecosystems in the tropical regions of Eastern Africa [14]. During 2019 in Afar Region, Shiferaw et al. [15] reveal that there were 1.2 million ha of *P. juliflora* invaded lands that expanded at the rate of 31,127 ha per annual. It established 12.3% of *P. juliflora* land surface invasions in Afar region. Moreover, other information of Pitroff [16] reported by Farm-Africa that *P. juliflora* invaded over 1.8 million ha in Afar region.

Several research works show that *P. juliflora* had environmental effects, which is aggravating and influencing invasions into various ecosystems [10] that significantly had weaken ecosystem services [17, 18]. It reduced palatable grasses of livestock and replaced grass species such as *Chrysopogon plumulosus, Cenchrus ciliaris* and *Setaria verticillata,* and valuable woody species *Acacia tortilis, Acacia Senegal,* and *Acacia nilotica*. *P. juliflora* resulted also in social instability and economic hardship, placing constraints on sustainable development, economic growth, poverty alleviation, and food security in Afar region [19–21]. It caused harm or is likely to cause harm to the environment, people, economy, or human health [22, 23]. *P. juliflora* pods fed by livestock caused tooth decay and death through indigestion in the absence of supplementary feeds in the dry seasons [24, 25]. In arid and semiarid areas, ecosystem services obtained from woodlands, rangelands, livestock production, groundwater, and benefits of conservation areas and tourism were also under threat [26].

In different parts of Ethiopia, so as to minimize and control the invasion of *P. juliflora*, different strategies were applied such as eradication through mechanical

methods and burning and cutting of the juvenile plant at 10 cm and adult plant at 40 cm down to the ground were tried by the Ethiopian Institute of Agricultural Research [27]. These methods were costly to manage the species. In addition, controlling *P. juliflora* invasion through utilization such as charcoal production and animal feeds were also tried [28, 29]. However, most of these efforts failed to control the species. Current management practices are also not satisfactory to sustain the rangelands and woodlands. *P. juliflora* management options counter to environmental effects are not sufficient to control its invasion progress toward rangelands and expand into other land use systems in the invaded regions of the country. Unless improved management interventions are adopted, the sustainability of ecosystem services will be at stake in near future. This paper aims to review the effects of *P. juliflora* on environmental constituents in Ethiopia, review the management options and take up lessons learned elsewhere or in Ethiopia, and review about the utilization and management of *P. juliflora*. Thus, this paper addresses relevant scientific information based on the evaluation of information collected from different journals, books, manuals, and various reports.

2. Review method

In this paper, relevant pieces of literatures were selected using the systematic review. Based on the specific objectives of the topic, journals, books, manuals, various reports, and related synthesized ideas were screened. Hence, 81 journals, 9 books, 5 proceedings, and 17 various reports were selected. In addition, except for the concept of some terminologies used, update sources were used for the review.

3. Environmental effects of *Prosopis juliflora*

Dense impenetrable thickets of *P. juliflora* compete with native plant species and harms environment thus disrupt ecosystem functions and services. The species affected soil properties, hydrology, land use and land cover changes, rangelands, quality and availability of animal feeds, threat to fertile agricultural lands and loss of their productivity, reduce biodiversity, invaded wildlife reserves and national parks, affect human and livestock health, the economy of the country and the overall livelihoods of pastoralists, social conflicts and cerate political instability, reduce bird diversity, blocks roads of both animal and inhabitants, reduce urban amenity, but induce carbon sequestration in the invaded areas (see **Table 1**).

3.1 Effects of *Prosopis juliflora* on soil environment

3.1.1 Soil physicochemical properties

Windbreaks, cover crops, and cultivation practices can control loss of soil [64]. Likewise, a shelter belt of *P. juliflora* is planted around fields in many semiarid regions to reduce wind speed and reduce wind induced soil erosion, decrease desiccation by reducing transpiration, and thereby increase plant and animal production [65]. These types of plantation using *P. juliflora* were also practiced in the invaded regions of Ethiopia. The capacity to block the flow of wind depends upon the height, density, and thickness of the stands of plantations. Apart from preventing the loss of fertile

Effects of *P. juliflora*	Authors
environmental harms	[21, 30, 31]
Disrupt ecosystem functioning and services	[14, 30, 32, 33]
Soil properties and soil seed bank	[30, 34–39]
Hydrology	[40]
Land use land cover changes	[41–46]
Rangelands, quality, and availability of animal feeds	[11, 21, 30, 32, 43, 47]
Productivity of agricultural lands	[30, 48, 49]
Loss of biodiversity	[30, 43, 48, 50]
Invade parts of wildlife reserves and national parks	[2, 32, 35, 47, 48, 51]
Human and livestock health	[2, 13, 30, 35, 43, 52, 53]
Effect economy and overall communities' livelihoods of a country	[2, 32, 54]
Social tensions or conflict	[29, 30, 36, 43, 55]
Political instability	[13, 17, 56]
Barrier to movements of the animal and human beings	[30, 43, 57]
Reduces urban amenity	[54, 58]
Reduces bird diversity	[43, 59]
Carbon sequestration	[30, 60–63]

Table 1.
Effects of Prosopis juliflora *on environmental properties and its environmental services.*

soil, *P. juliflora* reduced wind damage from crops, reduced loss of soil moisture, and improved microclimate. A report by Patnaik et al. [43] in Sudan shows that wind speed inside 5-year-old *P. juliflora* plantation reduced an average 14%, while potential evaporation reduced by 22% in the same site. *P. juliflora* was growing quickly, and it was a wind-resistant plant, which could be planted successfully to control soil erosion and could serve as shade and shelter that affected water balance by increasing relative humidity but reducing temperature and evapotranspiration [10]. On the other hand, in low land areas of Central Sudan, a study by Al-Amin et al. [66] shows that *Leptadenia pyrotechnica*l provided relatively good protection windward against consequences from erosion than cover of *P. juliflora*. This study shows protection of *P. juliflora* against soil erosion lower than the later species. Another study in Central Sudan by Al-Amin [67] reveals that the growth of *P. juliflora* in clusters could be more effective against wind protection than individual stems. *P. juliflora* had planted where soil fixing or improvement is an important consideration [68], 1). The authors also proved that *P. juliflora* was particularly suitable for stabilizing dunes and easily erodible soils. This is because of its ability to survive and grow on poor sites in which a few other species could tolerate, and its extensive lateral root system could bind soil particles particularly in the upper 60 cm soil depth.

Findings by Giessen et al. [69] show that *P. juliflora* enriched SOC, total P, total N, and available P under its canopies of topsoil in semiarid of Northeast Brazil. In Kenya, results by Mwangi and Swallow [24] reveal that biomass of understory plant species was five times lower under the canopy of *P. juliflora* than open grasslands. SOC and

total N concentrations in soils under *P. juliflora* were higher than those under open grassland areas. In Afar region of Ethiopia, a study by Shiferaw et al. [14] shows that invasion of *P. juliflora* changed the physicochemical properties in Teru and Yalow Woredas. Several findings show that positive effects of *P. juliflora* on soil properties overweight the negative ones. For instance, *P. juliflora* significantly affected soil pH, exchangeable Na^+, water-soluble Ca^{2+} + Mg^{2+}, water-soluble Na^+, and exchangeable Na percentages. The invasion of *P. juliflora* significantly increased soil pH but decreased exchangeable Na^+, exchangeable Na percentage, and water-soluble Ca^{2+} + Mg^{2+} than non-invaded open grazing lands. The clay content of *P. juliflora* invaded lands was higher than non-invaded open grazing lands. However, the sand content of the soil was higher under non-invaded grazing lands than *P. juliflora* invaded lands. In this study, though in most of the findings, the invasion of *P. juliflora* had positive effects on physicochemical properties, Shiferaw et al. [2] show negative effects on plant diversity, human and livestock health, economic losses, and it means that negative effects are outweighing its positive effects.

According to Sadeq et al. [35], SOC, total N, available P, total S, and total soluble salts were higher under canopy of *P. juliflora* than outside in soil depth of 0–45 cm, but total Na increased within this soil depth. In Kenya, Muturi *et al*. [70] show that soil characteristics such as %sand, %clay, N, P, K, Mg, Mn, Fe, and Cu under *P. juliflora* species and mixed species of *Acacia* and *P. juliflora* canopies were similar except that pH and calcium were higher under the *P. juliflora* species and mixed species of *Acacia* than under canopy of *P. juliflora*. But, in Turkwel riverine forest, silt and carbon were lower under *Acacia* canopy than under *P. juliflora*. In terms of soil salinity, neutralizing alkaline, sodicity, and soil nutritional status, physical properties such as soil moisture, bulk density, and soil texture, *P. juliflora* have ameliorating effects. These are primarily due to complex interactions between the effects of nitrogen fixation, incorporation of leaf litter, changes in microclimate, and changes in the floral soil fauna and soil microbial populations [10]. In Kenya, research by Kahi et al. [71] reveals that organic matter and total N were higher under *P. juliflora* canopy than under open areas. However, available P, soil pH, soil bulk density were lower under *P. juliflora* canopy than under open areas. Thus, growth of *P. juliflora* implications for creation of suitable soil microclimate probably due to litter turnover and its facilitation of infiltration and draw water from ground to surface soil.

3.1.2 Soil biological properties

Mehadi et al. [72] indicate that invasion of *P. juliflora* increased total mycorrhizal colonization of roots and reduced heavy metals such as Cadmium (Cd) levels in plants. In addition, the intensity of mycorrhization under canopy of *P. juliflora* was significantly higher than under species of native *Acacia*. Results in Saudi Arabia revealed that Cmic under *P. juliflora* was greater in rhizosphere for *P. juliflora* than in rhizosphere of *Acacia ehrenbergiana* and *A. tortilis*. As a result, extracts from parts of *P. juliflora* were used in disinfecting and bio-functions against different bacterial pathogens. But, litter fall of *P. juliflora* inhibited plant growth and their Arbuscular Mycorrhizal Fungi colonization of roots [34]. For instance, the litter and leaf extracts of *P. juliflora* significantly inhibited the germination of *Sorghum bicolor*. On the other hand, *P. juliflora* stimulated soil microbial biomass of carbon, soil metabolic quotient, and activities of soil enzymes.

3.1.3 Hydrology

Moisture and nutrients that were taken from deep soils under *P. juliflora* were beneficial to the herbaceous plants. The removal of trees from the savannah ecosystems during wet and dry seasons supported large numbers of grazers that facilitates the growth of herbaceous plants. But, during the dry periods, the survival of the shallow-rooted herbaceous plants could be endangered by removal of trees [71]. During this season, transportation of moisture from deep soil by trees was encountered in semiarid and arid regions. Extensive lateral root systems of *P. juliflora* capture surface water after rain, but its deep tap roots allowed them to survive prolonged drought through accessing the water table [10]. However, in dry areas, evapotranspiration of plants was escalated than their transpiration. For example, Shiferaw et al. [40] indicate the daily average transpiration of *P. juliflora* lower than the daily average evapotranspiration of a dense *P. juliflora*.

3.1.4 Soil seed banks

Soil seed bank is ground flora of various vegetation ecosystems. It is important for shaping the composition, diversity, structure, and regeneration of plant communities and consequently restoration of vegetation ecosystems. Soil seed bank depends on the spatial distribution of vertical and horizontal seeds of different species and vegetation communities. The spatial distribution of seeds in the soil is primarily a function of the dispersal process [73]. Dense thicket of *P. juliflora* hindered the dispersal of other seeds of other plant species in the invaded area. The seeds of *P. juliflora* were characterized by a seed coat-imposed dormancy and established a huge persistent seed bank in the soil. This character makes it easy and continues germination of seeds of the species. In addition, livestock and wild animals are attracted by the green foliage to eat ripened pods and disperse the seeds. Dispersal and successful germination of the seeds of *P. juliflora* were thus through endozoochory of animals' seed ingestion. Seeds subsequently dispersed away from the parent plant and the pods are easily transported by runoff [36].

Land use dynamics, struggle over resources, and change of climate are key factors that influenced the probability in the expansions of *P. juliflora* [2]. When an invasive species became irresolutely verified, its control can often be challenged and eradication is habitually not possible. Subsequently, its impacts on biodiversity, ecosystem progressions, and ecosystem services can be serious [36]. In vegetation ecosystems, the seed bank of soil has been considered as a promising and cost-effective method for reestablishing of other native plant species, but its influence factors have not been clearly understood [74]. Possibility of vegetation restoration from soil seed bank is usually dependent on its seed density and species composition [75, 76]. The increases in the invasion of *P. juliflora* in certain ecosystem inhibit free dispersal of seeds in other native plants. Therefore, seed dispersal determines species diversity, composition, and density of plant species. Studies show that both livestock and wildlife species played a critical role in the dispersal of *P. juliflora* that enhanced the arrival of its seeds and progress into other land uses [77]. These in turn affected the fate of seeds of other native plant species.

4. Effects on land use and land cover changes

In the introduced areas, *P. juliflora* invasion and expansion increased both in coverage of area and density of the species. At global level, PENHA [78] reported that land

covered by *P. juliflora* was 50 million hectares. In Africa alone, for example, the land covered was about 5 million hectares forming dense thickets of *P. juliflora*. In several African countries such as Kenya, Ethiopia, Sudan, Senegal, and South Africa, it had become an invasive species [10, 79]. In the Afar region in Ethiopia, *P. juliflora* is now threatening serious problems on pastoral areas where its invasion existed in four of five zones and 11 of 32 districts of the region. Among the five administrative zones of the Afar region, the Amibara woreda of Zone 3 is thought to be recognized as the starting point for the introduction and spread of *P. juliflora* [55]. This woreda was represented as a degraded semiarid ecosystem in the region [30, 80]. Zone 1 and Zone 3 were the two zones that severely invaded by *P. juliflora*, and it was expanded to the remaining zones [18]. Dubti, Asayita in Zone 1 and Mile, Gewane, Amibara, Gelealu, and Awash Fentale in Zone 3 were the most severely invaded woredas in Afar region. Reports also show that Zone 4 and Zone 5 were partly invaded woredas of Afar region.

EBI [8] reported that *P. juliflora* was threatening vegetation types including *Acacia-Commiphora* woodland, desert, and semi-desert scrublands in Afar Floristic Region. Within these vegetation types, habitats invaded by *P. juliflora* were river banks, irrigated cropland, roadsides, and the settlement areas [2]. *P. juliflora* displaced grazing lands and threatened wildlife conservation areas [47, 50, 81]. According to Helland [42], *P. juliflora* was associated mostly with the loss of pasture and invasion of woodlands. The major factors that aggravated and influenced invasions into various environments are the changes of land use and land cover and climate change [10], and increase in population pressure and overgrazing of pasture lands owing to large herding were also other causes for the increase of invasion of *P. juliflora* in invaded regions of Ethiopia [15].

5. Rangeland quality and availability of animal feeds

P. juliflora replaced local biodiversity in several spots in Afar rangelands and riversides [27]. In such habitats, the grasslands had no more used for grazing and ecosystem functions of rangelands were changed to thickets of *P. juliflora*. These made Afar pastoralists moved further from their home and pasture fields. As a result, these aggravated foods and feed shortage. Mitiku [82] reported that in Amibara woreda of Afar region, *P. juliflora* severely invaded dense *Acacia* woodlands, riverine forests, and agricultural lands. His results indicated that in 16 years (1986–2001) of land use, land cover changes by *P. juliflora* and displaced 9.91 km^2 areas of *Acacia* woodlands. Most households reported that invasion of *P. juliflora* into rangelands was more in Amibara woreda than in Awash Fentale [83]. These could be probability and the adaptability of the species and its first arrival in the earlier woreda than the later. Similarly, in border country Eritrea, study by Harnet [84] shows that the invasion of *P. juliflora* invaded both dry season and wet season rangelands and roadsides in lowlands. A study by Zarga [45] reveals household responses reveal that rangelands had taken over by *P. juliflora*. Moreover, in South Africa, Ndhlovu et al. [85] suggested wider areas of rangelands covered by *P. juliflora* invasions and reduced its grazing capacity.

6. Biodiversity

Invasive species are the second threats to global biodiversity loss next to the land use changes [86]. In the world, biotic invasions by alien plant species are considered as the major factors in biodiversity loss and endangered plant species. The reasons are the

natural bio-geographical barriers of oceans, mountains, rivers, and deserts provided that isolation of essential species that ecosystems to evolve have lost their effectiveness due to the increase in global economy [87]. Biodiversity loss aggravated particularly the decline of plants that had associated with deforestation, land degradation, climate change effects, land use dynamics, and spread of invasive alien plants. Some of these invasive species caused considerable disasters in dry vegetation and rangelands of East Africa [88]. In Ethiopia, invasive alien plants and other native invasive plants could affect entire ecosystem services. As a result, natural agro-ecosystems are largely affected by the invasive alien plants [89].

Enormous invasive alien plants indicate in the decline of threatened and endangered native species; because they changed ecosystem processes, change of vegetation structures, and shift native species for the reason that they reached high densities and biomasses [58]. In Afar region, Tessema [13] indicated that *P. juliflora* threatened native plant species such as *Acacia prasinata*, *Boswellia ogadensis*, *Euphorbia doeloensis*, *Euphorbia ogadensis*, and *Indigofera kelleri*. *P. juliflora* blamed for many disaster effects such as replacing grasses, herbs, and shrubs, which were consumed by local livestock, injured livestock with its poisonous thorns, and causing goat teeth to rot and fall out because the small seeds got stuck between the teeth. Thousands of goats had been toothless and died from starvation following teeth loss, which decreased their number and threatening goat breed [88].

7. Effects of *P. juliflora* on the habitat of wild animal

In Afar region, wild animals were endangered due to the disruption of ecosystem integrity. These habitats that harbor threatened plant species also harbored many globally threatened and vulnerable mammal and bird species [88]. It reduced the diversity of birds under the thickets of *P. juliflora* than adjutant non-invaded habitats [43]. But, the invasion of species caused for the loss of agricultural crops adjacent its thicket. This is probability the habitat harbor wild animals to hide in the thicket affected production of crops.

8. Health

8.1 Effect of *P. juliflora* on human health

P. juliflora thorns are dangerous and inflict pain that is like being bitten by a snake [21]. For instance, among human injuries, 8.4% in Awash Fentale and 5.2% household respondents in Amibara woreda reported that pricked by thorns of *P. juliflora* [83]. Furthermore, the studies also highlighted the complexity of the cause of Anopheles' relationship with invasive alien plants such as *P. juliflora* that increased malaria incidences [53, 90]. These have implications to the production of anopheles insect in thickets of *P. juliflora*, which threated human health in the invaded regions of the country.

8.2 Effect of *P. juliflora* on animal health

Due to the loss of quality pasture lands, thousands of goats have been rendered toothless and died from starvation following teeth loss, which has been decreased

their number [88]. Nevertheless, households in Awash Fentale and Amibara woredas replied that pods/seeds were the most palatable part of *P. juliflora* by animals [83]. Most of them argued that leaf of *P. juliflora* was the most toxic and killed their animals after consumptions [10]. This might be due to a permanent weakening of the ability to digest cellulose in pods and high sugar content of the pod that depresses the rumen bacterial cellulose activity and finally killed the animal. Feeding of *P. juliflora* pods was leading to neurological disorders, toxicity to neurons of cranial nerve nuclei leading to partial anorexia, depression, salivation, twitching, dehydration, and bloody diarrhea, bile duct hyperplasia, renal tubules, and there is rarefaction of lymphoid tissue, chronic and progressive injury to neurons, and causing denervation atrophy [43]. As a result, various plant parts of *P. juliflora* affected animal health and reduced their production in the invaded regions of the country.

9. Effects of *Prosopis juliflora* on the economy

9.1 Use of *Prosopis juliflora*

Introducing species to new locations had tremendous contributions to societal development [75]. Due to this, human welfare had improved the introduction of its parts out of its native ranges. Trade enabled modern societies to benefit from the unmatched movement and formation of species in the world [91]. Wood sources of *P. juliflora* were also used either as fuel wood or structural material. As a fuel, it could be burned directly or formed as charcoal, and timber, it can be used poles or formed into different types of furniture [24].

P. juliflora pods and seeds are consumed by a wide variety of animals, both in their native range and where it was hosted, and it is an important mammalian diet when trees were existent in large numbers [43]. For instance, a study by Ilukor et al. [92] in the Afar region of Ethiopia shows that households fed their animals with leaves and pods of *P. juliflora*. However, feeding animals that consumed only *P. juliflora* leaves and pods caused acrimonious milk and lost body weight of animals [93]. *P. juliflora* branches were widely used as fencing posts, while its pods high in protein and sugars were important food for human being [24]. *P. juliflora* species had also ameliorating effects on soil under natural and semi-natural systems because of nitrogen fixation and leaf litter incorporated into the soil improved physical and nutritional status of soil. These had reduced the use of inorganic fertilizers commercially purchased by land managers in the invaded regions. High mineral content and rapid decay of small leaves were favorable characteristics for the use of foliage as a soil ameliorant. Compost making could detoxify its allelochemical effects on germination and growth of plants [94]. In addition, when added to agricultural and forest fields, compost made from leaf of *P. juliflora* replaced the cost incurred to commercial fertilizers in various countries. Other uses of *P. juliflora* are flowers for the supply of nectar and pollen as bee forage to produce honey. Flower of *P. juliflora* is small, yellow, and gathered on long inflorescences producing pollen and nectar that is high in protein and sugars [43]. Although *P. juliflora* has diverse economic values, the use of the plant is limited. In Ethiopia, for example, local communities in the invaded areas used the plant only for animal feed, fuel wood, charcoal, and construction purposes [2]. These indicate that *P. juliflora* was underutilized in the

invaded areas of the country that made it easy invasion and threatened vegetation ecosystems and affected native plant species.

10. Effects of *Prosopis juliflora* on grazing lands

In animal-rearing areas of lowlands, pressures on environment caused living incomes make dynamics, which improved demands and concentrated supplies of natural resources owing to the upswing of population. Widespread rearing of livestock and crusade in search for feed and water, resource use for charcoal production and construction materials, and shortage of institutional capacity levied influences on present natural resources particularly on woodland vegetation. These caused devastation and deprivation of the vegetation resources in the invaded areas [95]. As a result, the socioeconomic and ecological impacts of *P. juliflora* on grazing lands became severe [13]. *P. juliflora* is the source of income for the poor, but has damaging effects for pastoralists and rich people by slaying their animals and attacking their rangelands [82].

11. *Prosopis juliflora* versus social conflict and political instability

Reports show that invasion of *P. juliflora* might lead to serious food insecurity and might even trigger tribal conflicts for the remaining few pastures and farmlands [13, 19]. This resulted in the taken over of grazing lands by the *P. juliflora* aggravated by climate change and has been caused border conflicts and political instability, for example, between Afar clan and *Issa* of Somali on the border of the two regions. The combination of diminishing grazing areas and population growth both human and animal has contributed to land degradation, competition for pasture and water, and interethnic and intra-ethnic conflict. These factors have favored the invasion of *P. juliflora* in the invasion region [96]. Furthermore, Rogers et al. [97] reported that impacts of *P. juliflora* interact with other drivers of vulnerability. Pastoralists report had broadened conflict, complicated relationships with the state, and increased decentralization within invaded areas of southern Afar of Ethiopia. In Kenya, some individuals, from Chemonke village, claimed to have been displaced from their original settlements by *P. juliflora*. They had to seek alternative settlements elsewhere sometimes imposed them to lease land for cultivation in their new areas. Conflicts might rise as the displaced areas, which seek alternative settlements [24]. A report by FAO [57] further pointed out that invasion of *P. juliflora*, climate, conflict, and economic shocks were among the causes of political instability and the main drivers of food insecurity in Somalia in East Africa.

12. Deterioration of urban amenity by *Prosopis juliflora*

P. juliflora in its native range in Mexico is described as an urban afforestation program that would mitigate air pollution by planting with other native species [98]. But it deteriorates ecosystems in its exotic land ranges in tropics such as Asia and Africa. *P. juliflora* is an aggressive invader of urban fallows and abandoned fields that deteriorate its beauty [99]. Pasiecznik et al. [43] pointed out that *P. juliflora* does not fulfill all the qualities required for urban trees. It disrupts urban amenities in towns (**Figure 1**).

Figure 1.
P. juliflora *disrupts urban beauty in Melka Sedi (left) and Awash Sebat (right), Southern Afar region in Northeast Ethiopia.*

13. Blockade of roadsides by *P. juliflora*

A Report by Patnaik *et al*. shows that invasion of *P. juliflora* creates impenetrable thickets, which could be seen encroaching upon roadsides and blocking the roadsides resulted in human dwellings and blocking pathways (**Figures 2** and **3**) and seriously aggravate road accidents in (**Figures 3** and **4**). As indicated, the growth of *P. juliflora* moderately invades roadside next to wetlands and homesteads [50, 82]. These could be homesteads and wetlands have better organic matter and moisture for its establishment and growth. Due to the thorns of *P. juliflora*, these thickets can seriously aggravate a road accident and human and livestock movement to their homes and water sources (**Figure 5**). The invasions of *P. juliflora* block access to water sources, irrigation canals, homesteads, and blocked paths in Garrisa of Kenya [100]. Findings by Esther and Brent [101] in Kenya and Koyira [50] in Afar of Northeast Ethiopia show that the invasion of *P. juliflora* blocked trails and roads used by humans and livestock.

Figure 2.
Typical scenes of P. juliflora *advancing toward human dwellings (left) and blocking pathways (right).*

Figure 3.
Encroachment of Prosopis juliflora *in a wetland (left), and typically impenetrable thickets formed by the species (right). Due to the thorns contained in* P. juliflora*, these thickets can seriously aggravate a road accident.*

Figure 4.
Encroachment of P. juliflora *in a wetland (left), and typically impenetrable thickets formed by the species (right) in Kebena site of Awash Fentale Woreda in Afar region, Northeast Ethiopia. (Source photos: Shiferaw, 2017).*

Figure 5.
P. juliflora blocks paths to water sources in Melka Sedi, Southern Afar region in Northeast Ethiopia (Photo: Shiferaw, 2019).

14. Allelochemical effects of *P. juliflora*

Analysis of chemical extracts showed that allopathic compounds are phenolic or antioxidant capability in nature. Sluggish in breakdown and heavy buildup of leaf litter below *P. juliflora* may result in the increase of toxic substances in the soil layers, hindering the growth of other plant species [102, 103]. For instance, report by Kaur et al. [104] shows that there was a noticeable accrual of litter beneath the thicket of *P. juliflora* compared with *P. juliflora cineraria* in the hyper-arid habitats. Studies by El-Keblawy and Al-Rawai [103] reveal that lower species richness, evenness, and frequency of native species in plots under shades of *P. juliflora*. However, it had no allopathic effect on its seedlings growing below its canopies. But, Muturi et al. [70] show *P. juliflora* canopy hindered regeneration of other native species. Findings by Samuel et al. [105] depict that leaves of *P. juliflora* have greater inhibitory effects than its roots and barks. Muturi et al. [70] also indicated that bark contained the least inhibitory composites. But, shoot and root growth introverted by leaf and root extracts at higher application and concentrations. *P. juliflora* had both positive and negative interactions with plant communities in naturalized areas [2, 13, 23, 24, 50, 105]. Several studies carried out in many parts of the world show that problems of *P. juliflora* were outweighing positive ones ecologically, socioeconomically, and in all health aspects. However, some studies indicate that above-ground biomass, frequency, and cover of understory plant species were significantly higher under non-invaded grazing lands than under the shades of *P. juliflora* [71].

15. Understandings for the management of *P. juliflora*

A study by Shanwad et al. [106] indicates that control of *P. juliflora* is extremely difficult and costly for eradication once it invaded ecosystems. Report by Pasiecznik et al. [43] also confirmed that once *P. juliflora* established into large areas, prevention of further spread is not possible as the species quickly builds up soil seed bank. Thus, it required regular removal of all new seedlings over very many years, as seeds could remain viable for more than 40 years [31]. To control its invasions, different strategies can be applied such as eradication by utilization and mechanical control of *P. juliflora*. The potential irreversibility of the damage of invasion costs and may impose countries economic losses for management. The main management reactions after an alien species invaded are mitigation and adaptation [91].

To reverse the situations, integrated management strategies, participation of all stockholders and multidisciplinary research approaches within and across countries should be designed. To control invasive alien plants, various management options are tried but barriers faced for management in developing counties like Ethiopia [2]. In the invaded areas, experiences indicate that there are several methods of *P. juliflora* management. Chemical, mechanical, biological, management by utilization, and disrupting phenology of *P. juliflora* are among the management methods to control the species. There are three methods for the control of *P. juliflora* namely mechanical, chemical, and biological strategies [30]. Control of *P. juliflora* by utilization is an effective control way and management. In the following subsections, the pros and cons of management and control of *P. juliflora* invasions are discussed.

15.1 Chemical control methods for *P. juliflora*

Several available herbicides were tried to control *P. juliflora*. For example, the study by Shanwad et al. [106] shows combinations of chemicals reduced growth and development of *P. juliflora.* In their study, Mera-71, 2, 4-D ester followed by paraquat was the best in affecting weed recovery. The control of the regrowth of *P. juliflora* was effectively achieved by two times applications of systemic trans-located herbicides like Mera-71 (Glyphosate) and 2, 4- compared to paraquat, diuron. Controlling *P. juliflora* through chemicals at juvenile stages is highly effective than adult stages. Eradication of *P. juliflora* has been attempted in several countries through chemicals but has proved unsuccessful and chemical eradication is not environmentally friendly [107]. In, Ethiopia this management strategy was also tried to control *P. juliflora* but failed to manage it.

15.2 Mechanical control methods of *P. juliflora*

The mechanical control of *P. juliflora* is very labor-intensive, expensive, and economically feasible only for high-value lands. Mechanical control method of *P. juliflora* plant was recommended to cut at 10 cm for young trees and 40 cm for matured stems to control coppicing (**Figure 6**). Control of the spread of the *P. juliflora* is ineffective to eradicate it by mobilizing communities. Management of *P. juliflora* by utilization such as fuel wood, construction, and charcoal production, feed livestock by crushing pods are the best management options [57, 93]. But small-scale households cannot afford to control using mechanical methods. Pastoralists, agro-pastoralists, and urban dwellers should also manage their territory of rangelands, woodlands, homesteads, and compounds through hand weeding of *P. juliflora* seedlings. This method can minimize its invasion before it takes roots in different land uses. However, some of these methods need labor costs for control. Since cutting promotes regeneration, all mechanical methods of control cannot be recommended [107]. This management strangely was largely applied in Ethiopia to control the invasion of *P. juliflora* in Afar and Somale region, but did not succeed.

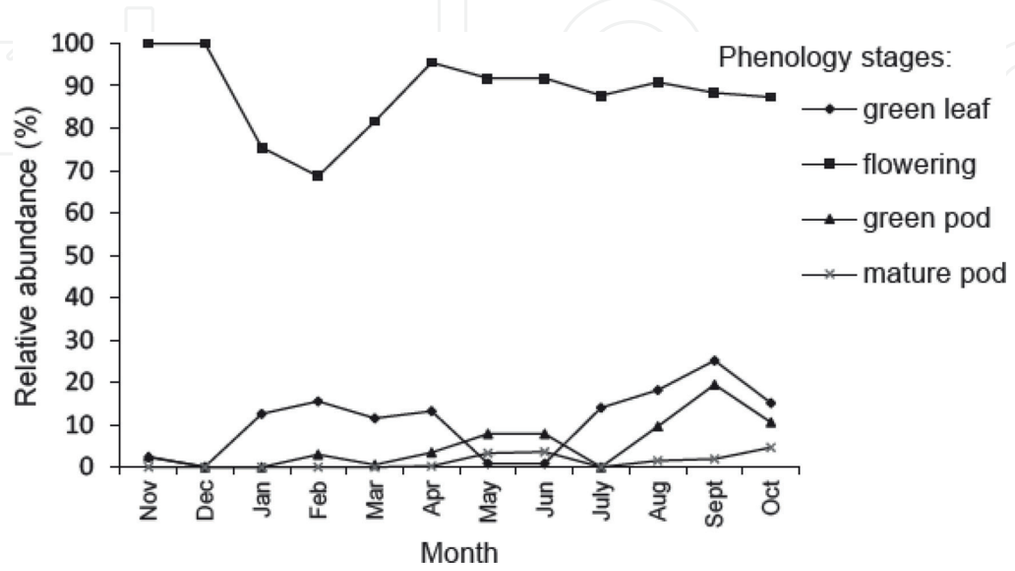

Figure 6.
Phenological patterns of P. juliflora in the Awash Fentale and Amibara Woredas, Afar region of Ethiopia in 2016/2017 cropping season. (Source: Shiferaw et al. [83]).

According to Shiferaw et al. [83], disrupting the phenology of *Prosopis juliflora* or aborting the juveniles of the species throughout the year, particularly during the peak time of flowering before seed set could also be used for the management *P. juliflora*. This method controls the species before it disperses seeds into the soil stores as a soil seed bank (**Figure 6**). These needs forced community involvement during its flowering times like yearly voluntary and community participation in soil and water conservation works in Ethiopia. During floral removal, care should be taken due to the allergy to its pollination.

According to Pantaik et al. [10], pollens of *P. juliflora* trigger allergic asthma, rhinitis, and skin allergy. Defoliation of only the leaves of *P. juliflora* also inhibits photosynthesis of the species (**Figure 6**). But, this method of destruction of leaf parts needs care not to cut the branches as *P. juliflora* aggressively propagates by all parts of its stems. Appropriate silvicultural techniques (e.g., thinning) of *P. juliflora* should also be practiced to lessen the invasiveness and effects on other plants [55]. For instance, a research by Singh et al. [108] shows that plant height was recorded to be 20 and14% higher in *P. juliflora* and *A. nilotica* respectively grown in combination with grasses than the sole plantation of these species applying a silvicultural treatment of *P. juliflora*. Moreover, Walter and Armstrong [109] reported that proper silvicultural management increased the quality of wood for maintaining its benefits for livelihood and control the invasion of *P. juliflora*. This management strategy could not be tried in Ethiopia at large to control the progress of *P. juliflora* into various vegetation ecosystems to enhance the values we get from ecosystem services.

15.3 Biological control methods of *P. juliflora*

In recent decades, biotic control has increased recognition in various countries due to lucrative and reliable means of managing large invasiveness of alien plants. It comprises the restrained, strictly administered introduction of one or more species of highly studied alien organisms that blizzard from the original home ranges of invading plant species, and which physiologically are reformed to feeding absolutely on or attacking completely plants of that [30]. In Africa, though the goal of cooperation for biological control of *P. juliflora* in South Africa with other countries, it delayed trendy due to the controversy for the introduction of biological control agents onto *P. juliflora*. Additionally, debates about the relative value and costs of trees continued to hinder progress with the planned increase of biological control [110]. Ravhuhali et al. [111] concluded that managing the spread of invasive species could also be accomplished using livestock as biological control while improving the productivity of the animals (e.g., *P. juliflora* pods utilized for livestock feed ingredients with other feeds). The release of bio-control agents was also considered where these technologies were not feasible because careless release in some species might escape and change into invasiveness inclining to threaten the native organisms [107]. These strategies were not largely tried on research fields of Ethiopian Agricultural Research Institutes, for instance, and had no theories in management of *P. juliflora* in the invaded areas of Ethiopia.

16. Conclusions

P. juliflora has effects on the soil environment in the form of allelochemicals that are ingredients in its plant parts that have effects on living organisms, take over land

uses land cover aggressively, economic loss, the health of humans and animals, and reduce the diversity of organisms. On the other hand, the species is used to ameliorate soil properties (soil physical, biological properties), e.g., sequester CO_2 for mitigation of greenhouse effects, and other economic values (construction materials, furniture, medicinal values, sources of pollination for honey production, and animal feeds, etc.) particularly in the semiarid and arid tropics. However, the negative effects of *P. juliflora* exceed its positive values. Mechanical, chemical, management by utilization, fire regime, disrupting its phenological stages, and biological control methods have their pros and cons to control *P. juliflora*. Therefore, prevention, integrated management strategies, and management of the species by utilization are the best measures used to control *P. juliflora* recommended globally and in Ethiopia. Mechanical methods (aborting phenological stage, utilization of the species, others) need awareness of the communities, and forced mobilization is vital for effective and efficient management of the species.

Previously, in several countries, the management methods, namely mechanical, chemical, and biological, were being tried to control the alien *P. juliflora*. But all the methods failed to eradicate the species. As a result, the species is continuing to invade and take valuable farmlands, grazing lands, rural homesteads, wetlands, roadsides, and urban areas, particularly in Afar and Somali regions. In Ethiopia, more research involving multidisciplinary research approaches should be designed to conduct the effects of *P. juliflora* on the environment, economy, and health of animals and communities. Moreover, other teams should also design other effective and efficient management designs that are different from previous researches that is vital to alleviate the invasion of the species and thus improve the livelihood of inhabitants in the region.

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Conflict of interest

The authors declare no conflict of interest.

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