Review [Revisión]

Prosopis juliflora L: DISTRIBUTION, IMPACTS AND AVAILABLE CONTROL METHODS IN ETHIOPIA[1]

[*Prosopis juliflora* L: DISTRIBUCIÓN, IMPACTOS Y MÉTODOS DE CONTROL DISPONIBLES EN ETIOPÍA]

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SUMMARY

Prosopis juliflora, an evergreen shrub, is one of the most invasive alien species causing economic and environmental harm in arid and semi-arid areas. It is spreading rapidly in the rangelands, croplands and forests and in particular is threatening pastoral and agro-pastoral livelihoods. *Prosopis* has invaded parts of wildlife reserves and National Parks threatening biodiversity. There are several factors favoring its rapid distribution in the environment. Its ability to adapt wide range of climatic condition, effective dispersal mechanism, its allelopathic effect, prolific nature, having large seed bank in the soil environment, fast growing and vigorous coppicing ability are among the principal factors. *Prosopis* has the capacity to decrease the composition and diversity of plant species and it has adverse effects on crop yield, as well as animal and human health. Despite its negative effects, the tree has potential uses such as fuel, charcoal, fodder, food, bio-char, bio- control, windbreaks, shade, construction and furniture materials, and soil stabilization. It can be also be used against different disease and ameliorated environmental conditions through carbon sequestration. On the other hand, manual, mechanical, chemical and biological control methods as well as control by utilization have been pointed out as an effective control ways and management of this weed. There is urgent need to develop management strategies that are environmentally friendly and economically viable to bring them under control. Therefore, objective of this review was to explore the distribution, impacts, benefits and as well as the possible management approaches against *Prosopis*.
Key words: Allelopathy; beneficial effects; distribution; impact; *Prosopis juliflora*.

RESUMEN

Prosopis juliflora, un arbusto de hoja perenne, es una de las especies exóticas más invasivas que causa daño económico y ambiental en áreas áridas y semiáridas. Se está extendiendo rápidamente en los pastizales, tierras de cultivo y bosques y, en particular, está amenazando los medios de vida pastoral y agro-pastoral. Prosopis ha invadido partes de reservas de vida silvestre y parques nacionales amenazando la biodiversidad. Existen varios factores que favorecen su rápida distribución en el medio ambiente. Su capacidad para adaptarse a una amplia gama de condiciones climáticas, mecanismo de dispersión eficaz, su efecto alelopático, su naturaleza prolífica con un gran banco de semillas en el suelo, el rápido crecimiento y capacidad de rebrote vigoroso están entre los principales factores. Prosopis tiene la capacidad de disminuir la composición y diversidad de especies vegetales y tiene efectos adversos en el rendimiento de los cultivos, así como en la salud animal y humana. A pesar de sus efectos negativos, el árbol tiene usos potenciales tales como combustible, carbón vegetal, forraje, alimentos, bio-carbón, bio-control, cortavientos, sombra, materiales de construcción y mobiliario y estabilización del suelo. También puede utilizarse contra diferentes enfermedades y mejorar las condiciones ambientales mediante el secuestro de carbono. Por otro lado, los métodos de control manual, mecánico, químico y biológico, así como el control por utilización, han sido señalados como un medio eficaz de control y manejo de esta maleza. Es urgente desarrollar estrategias de manejo que sean ambientalmente amigables y económicamente viables para controlarlas. Por lo tanto, el objetivo de esta revisión fue explorar la distribución, los impactos, los beneficios y los posibles enfoques de manejo contra Prosopis.
Palabras clave: Alelopatía; efectos benéficos; distribución; impacto; Prosopis juliflora.

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INTRODUCTION

*Prosopis juliflora L. (*here in after referred to as *Prosopis*) is one of the world's worst woody invasive plant (Berhanu and Tesfaye, 2006; Ros *et al*., 2014), which is an evergreen, fast-growing mimosa tree or shrub, native to Mexico, South America and the Caribbean. The plants forms impenetrable spiny thickets, and at maturity reach a height of 12 meters with trunk diameter of 1.2 meters (Berhanu and Tesfaye, 2006). Currently, *Prosopis* has become the worst weed in Pastoral and agro-pastoral communities of Ethiopia, Kenya and generally in the eastern part of Africa (Mwangi and Swallow, 2008; Maundu *et al*., 2009). According to assessment made by EIAR and other national and international organizations, *Prosopis* is number one priority invasive weeds in Ethiopia (Sertse and Pasiecznik, 2005).

Existing evidence suggests that *Prosopis* was introduced to Ethiopia in the early 1980s purposely for the sake of tackling the challenge of desertification in over grazed arid and semi-arid areas of Eastern Africa by some multi-national development agencies (Rettberg and Müller-mahn, 2012). Since then in terms of coverage, the areas' most adversely affected nationally include the Afar and Somali Regions in the east and southeast of the country and the area around Dire Dawa city. There are also moderately affected areas in Amhara, Oromia, Southern Nations Nationalities and Peoples (SNNP) and Tigray Regions that is, in the mainly dry lands of Central, East and North Ethiopia (Steele *et al*., 2009). Above all, the worst thing is its negative impacts on the ecosystem like forming impenetrable shrubby thickets, invading water courses, lowering the water-table and thus indirectly starving plants of other species of moisture and nutrients, creating what are known as 'green deserts', largely devoid of life, instead of meeting the stated objective (Gordon and Arne, 2013).

The rapid expansion of *Prosopis* is considered as a major threat mainly for pastoralist livelihood in the environment due to its invasive nature. It can infest pasturelands, irrigated cultivated lands and irrigation canals, finally causing an irreversible displacement of natural pasture grasses as well as native tree species (Kassahun *et al*., 2004). Its negative effects include inhibiting the ecosystem alone by displacing beneficial native species; encroachment onto paths, villages, homes, water sources, crop- and pastureland; and injuries due to thorns that impacted animal and human health apparently resulting in some human fatalities (Mwangiand Swallow, 2008; Maundu *et al*., 2009). Forage grass productivity and rangeland drastic degradation can happen due to an invasion of *Prosopis*. Soil erosion and a loss in livestock productivity have been the consequences, leading to fewer and lower quality rangeland sites available to pastoralists (Wakie *et al*., 2012; Ayana and Oba, 2008; Gerber, 2012). *Prosopis* outcompetes important forage species and, thus, reduces long-term forage availability and, hence, the sustainability and quality of livestock production (Mueller-Mahn *et al*., 2010).

Despite its negative effects, *Prosopis* invasions generate environmental, social and economic benefits (Wise *et al*., 2012). This has led to contentious issues surrounding the genus (Richardson, 1998*b*; van Wilgen and Richardson, 2014). Some advocates promote it as a 'wonder plant' while others call for its eradication, or contrast its positive and negative aspects, e.g. 'Boon or bane' (Tiwari 1999). Yibekel (2013) reviewed the Ecological and Economic Dimensions of the Paradoxical Invasive Species *Prosopi juliflora* and Policy Challenges in Ethiopia. He noted that there has not been clear policy or strategy towards *Prosopis* or to invasive species management in general. *Prosopis* is recognized as a major threat to biodiversity and economic wellbeing of society by plans such as the Environmental Policy of Ethiopia (EPE) and the Biodiversity Strategy and Action Plan (NBSAP) and Forest Resource Strategy of the country (IBC, 2005). In contrary to this plans, however; the National Action Plan of the country recommended *Prosopis* tree as a potential tree to combat desertification (Anagae *et al*., 2004; Environment Protection Authority, 1998) signifying the existing policy dilemma towards *Prosopis*.

Contrasting views, contradictory perceptions and unclear policies are limiting options for constructive dialogue between different parties. This is exacerbated by problems in identifying and differentiating morphologically similar species, and by a general lack of knowledge on the distribution, scale of invasion, benefits, impacts and effective management approaches. This paper was designed to undertake an overview of *Prosopis* to act as a prerequisite for proposing holistic management strategies of the species in Ethiopia. This review could be useful for guiding and prioritizing management and improving knowledge in other groups of woody invasive plants (Kull *et al*., 2011; Wilson *et al*., 2011). Therefore, the objective of this review was to explore the occurrence, potential distribution, harmful and beneficial effects as well as the available controlling measures against *Prosopis.*

Ecological Distribution of *Prosopis juliflora*

Prosopis is a shrub which is native to Mexico, South America and the Caribbean (Berhanu and Tesfaye, 2006). It is an evergreen shrub which has extensive root system which can reach up to 40 cm in just eight weeks, and grows quickly after germination (Pasiecznik, 2002). This characteristic of *Prosopis* helps it to invade new regions. It is found as an invasive weed in Ethiopia, Kenya, Sudan, Eritrea, Iraq, Pakistan, India, Australia, South Africa, the Caribbean, the Atlantic Islands, Bolivia, Brazil, the Dominican Republic, El Salvador, Nicaragua, the United States (USA), and Uruguay (Iqbal and Shafiq, 1997; Pasiecznik *et al*., 2001; Bokrezion, 2008). It has become established as a weed in Asia, Australia, and elsewhere. It is fast-growing, nitrogen-fixing, and tolerant to arid conditions and saline soils (Anonymous, 2003, Pasiecznik *et al*., 2004).

In Ethiopia, *Prosopis* was introduced in the late 1970's through collaborative efforts of governments and international development organizations to rehabilitate degraded soils, to supply firewood and fodder and to combat desertification (Berhanu and Tesfaye, 2006; Shackleton *et al*., 2014). However, the species rapidly naturalized and expanded into new locations, where it was neither anticipated nor desired. It was first observed in Dire Dawa at Goro Nursery site probably introduced from India (EARO and HADRA, 2005). Now a day, around one million hectares of Ethiopia are already covered by *Prosopis* (Ryan, 2011), of which about 700,000 ha are located in the Afar Region (Mueller-mahn *et al*., 2010). In terms of coverage the most adversely affected areas nationally include the Afar and Somali Regions in the east and southeast of the country and the area around Dire Dawa City. There are also moderately affected areas in Amhara, Oromia, Southern Nations Nationalities and Peoples (SNNP) and Tigray Regions that is, in the mainly dry lands of Central, East and North Ethiopia (Steele, 2009).

According to Rezene *et al*. (2011) *Prosopis* is spreading rapidly in various rangeland areas and farm lands of Gambella, Oromia, Afar, Amhara and Somali national regional states which affecting crop production severely. It is also reported that high abundance of *Prosopis* at Fantale followed by Boset and Adama districts of East Shewa zone (Niguse and Amare, 2016). But no infestation was observed in west Arsi zone. Few young plants of *Prosopis* were observed at Wonji and Awash Melkasa towns which were intentionally planted for shade. In Adama district, around Sodare (Tourist attractive recreational area) were highly infested with prososopis tree (Niguse and Amare, 2016). Berhanu and Nejib (2016) reported that there has been an urgent need towards the management of *Prosopis* weed in Arba Minch zuria and Nyangtom districts, before it further spread to Nech Sar and Mago National Park, which is a home of plants' diversity. Yohanes (2014) informed that *Prosopis* is spreading rapidly even in the highlands of Ethiopia where it was not reported previously.

Study by Berhanu and Nejib. (2016) showed that Gamo Gofa, Segen Area People and South Omo zones along the main road and both sides of the road were covered by *Prosopis*. it was not only restricted to the infested Districts but also spread to non-infested Districts like Arba Minch zuria and Abaya Districts of Gamo Gofa Zone (Baleyneh *et al*., 2016). It is also found in Dollo Odo, Liben Zone and neighboring localities and many areas in the Wabi shebelle basin, present in Raya Azebo plains and going down the escarpments of Alamata in southern Tigrai and neighboring localities of North Welo, very abundant in Borena Range lands and neighboring localities, present in Dire Dawa city (Rezene *et*. *al*., 2011). *Prosopis* is aggressively invading pastoral areas in the Middle and Upper Awash Basin and Eastern Hararge (Mwangi and Swallow, 2005). It is also frequent in Arba Minch town and neighboring localities, very abundant in Liben, present in Areas of South Omo valley and across borders of Kenya (Rezene *et al*., 2011).

The highly invasive nature of *Prosopis* is a result of several factors; it is extremely drought resistant, a quality mainly attributed to its deep taproot (Samuel *et al*., 2013; El-Keblawy and Al-Rawai, 2005). The species can grow in a wide range of conditions ranging from sand dunes to clay soils; from saline to alkaline soils; from areas below 200 to more than 1500 m above sea level; and from 50 to 1500 mm mean annual rain fall (Pasiecznik *et al*., 2004; Zeila *et al*., 2004). It can also withstand and survive temperatures from as high as 50°C (air temperature) and 70°C (soil temperature) (Pasiecznik *et al*., 2004). Interspecific hybridization also enhances invasiveness in many introduced regions (Zimmermann, 1991). These functional properties of *Prosopis* and other foster its adaptability and support the invasion of the species across various agro-ecosystems including wetlands, dry lands, and irrigated agricultural lands (Shiferaw *et al*., 2004).

The other factors that make many *Prosopis* species successful invaders include the production of large numbers of seeds that remain viable for decades, rapid growth rates, an ability to coppice after damage, effective dispersal mechanism (Felker 1979; Shiferaw *et al*., 2004), root systems that allow them to efficiently utilize both surface and ground water (to depths of >50 m) (Nilsen *et al*., 1983; Dzikiti *et al*., 2013). Pod production is nearly continuous, so long as the plant has sufficient supply of water. Dry pods are palatable to domestic and wild animals. Seeds are hard, smooth and easily pass through the digestive system of most herbivores, which are the main agents of dispersal. In addition, its seeds pass through the digestive system of animals that feed on the pods, enter the soil through animal feces, and form a seed bank that is ready to germinate when conditions are favorable (Berhanu and Tesfaye, 2006; Shiferaw *et al*., 2004). Typically, such seed banks are difficult to manage and may persist longer than individual lifetimes of the organism itself (Hastings *et al*., 2007).

Shiferaw *et al*. (2004) working in Awash Rift Valley area, north-eastern Ethiopia found that a kg of seed had 36,000–37,000 seeds; a kg of goat droppings could have as many as 760; and that of cattle is 2833 seeds. Pod production is nearly continuous, so long as the plant has sufficient supply of water. Dry pods are palatable to domestic and wild animals. Seeds are hard, smooth and easily pass through the digestive system of most herbivores, which are the main agents of dispersal. Once in soil, seeds can lay dormant for a long time until favorable conditions return. In Awash, the total mean soil seed density in the litter layer and down to 9 cm depth was 1932 seeds/ m^2. About 37% of seeds found in goat droppings were still viable (Shiferaw *et al.*, 2004). Large numbers therefore germinate and growth is fast, aided by the animal manure.

High coppicing ability and effective dispersal mechanism is also another factors that help for its invasion. Once damaged through cutting or fire, the plants re-sprout with vigor, such that within two to three months it forms a thicket once more. Livestock, camels and goats play a significant role in spreading of *Prosopis* seeds via their faeces (Shiferaw *et al*., 2004) by carrying them into different areas. Rivers and water canals also play a significant role in the dissemination of seeds to different areas. Swamp areas, road sides and irrigation canals are highly invaded by *Prosopis*. This shows *Prosopis* establishes well in areas where water is available and also where surface runoff water present for its seed dispersal. This may be also the reason why *Prosopis* invaded most of the area along river Awash in the rift valley.

In addition to the above characteristics, the species also possess allelopathic and allelochemical effects on other plant species (Elfadl and Luukkanen, 2006; Essa *et al*., 2006). The number of annual plants significantly reduced under the canopy of *Prosopis* (Essa *et al.,* 2006). The plant has little or no self allelopathic (auto-inhibition) effect under field condition (EI-Keblawy and AI-Rawai, 2006). This mechanism, combined with drought condition can inhibit other species and eliminate any kind of competition. Throughout its growth *Prosopis* retains its ability to choke other plants and to prevent seedlings from germinating underneath it (Samuel *et al*., 2013; Clovis *et al*., 2014). *Prosopis* easily colonizes bare ground to stand out as the only plant. Cyanogenic glycoside, poisonous to animals such as cattle, has been found (Smolenski *et al.,* 1981). The leaves are unpalatable to most animals and this, along with the strong thorns, keep browsers away from the plant itself and, which in turn helps to reduce the pressure on the species and increase its invasions.

Impacts on human and animal health

Different studies have shown that *Prosopis* is known to inflict physical injuries on animals and human health apparently resulting in some human fatalities (Mwangi and Swallow, 2008; Maundu *et al*., 2009). *Prosopis* also has an effect on human health, and the most important effect of *Prosopis* on human health is that its thorns causes itching are inflicting wounds on legs, hands causing, lameness and even amputation of legs and hands due to infection of wounds. Its thorns can wound eyes and even cause blindness (Senayit *et al*., 2004). The thorn of *Prosopis* on penetrating the eye or skin of animals causes more inflammation than expected from the physical injury. An injury from the thorn of this species does not heal easily despite intensive medical treatments. The irritation may be due to waxes (Sharma, 1981). The local inhabitants are severely affected by injury from the thorns of *Prosopis* and are complaining about its rapid colonization of the area. Children feeding on the *Prosopis* pods are suffering from impaction and constipation (Herrie, 2014).

Using the wood in a fireplace can also cause dermatitis (Duke, 1983). Peoples are also being prayed by lions and hyenas, which are breeding and hiding in the *Prosopis* thicket, and is also associated to increase in malaria cases in the invaded areas (Berhanu and Tesfaye, 2006, Mwangi and Swallow, 2008; Herrie, 2014).

The negative effects also include complete loss of pasture and rangelands for both domestic and wild ruminants, losses due to access to water, and illness and death of livestock due to eating *Prosopis* pods and being pierced by the sharp and stout thorns. Although the seed pods of *Prosopis* are indeed palatable to livestock, the chemical content is thought to cause problems for goats, cattle, camel. A diet high in pods can cause mortality in sheep and goat by inducing a permanent impairment of the ability to digest cellulose (Duke, 1983; Lewis and Elvin, 2004). Cattle can die if they feed heavily on *Prosopis* leaves only over a prolonged period of time owing to its tannin contents (Mwangi and Swallow, 2005). Study by Senayit *et al*. (2004) reported that thorns damage eyes and hooves of camels, donkeys and cattle with poisons eventually leading to death of animals. Study by Berhanu and Tesfaye (2006) also showed that ingestion of the pod over long periods of time will result in death of cattle. Stomach poisoning by the pod may induce a permanent impairment of the ability to digest cellulose and, this might be due to the high sugar content of the pod that depresses the rumen bacterial cellulose activity and finally killing the animal (Berhanu and Tesfaye, 2006). It is also reported that excess accumulation of the pods (seeds) after feed causes death to goats and camels (Shimles and Getachow, 2016). Therefore, care should be taken while using the pods as domestic animals feeds.

Prosopis causing problems to livestock breeders because camel consumption of leaves lead to their sickness, eating their solid seed pods may result in falling out cattle teeth and reduction of their ability to graze. Similarly, the consumption of *Prosopis* leaves by camels' causes flatulence, diarrhea and sometimes constipation and thorns of *Prosopis* are harmful to livestock (Abdillahi *et al*., 2005). Furthermore, the invasion of *Prosopis* increased health risks due to higher exposure to predators, constrained access to water points and the emergence of new fatal animal diseases like "Harmaku", resulting from cytotoxins damaging the neurons of the intoxicated animals (Silva *et al*., 2007).

Impacts on pasture productivity and agriculture

Prosopis invasion can be devastating; rangeland areas have been degraded and forage grass productivity has declined drastically as a result (Wakie *et al*., 2012; Ayana and Oba, 2008). In areas where they spread, it has destroyed natural pasture, displaced native trees, and leading to fewer and lower quality rangeland sites available to pastoralists (Gerber, 2012). Study by Zeraye (2015) and Niguse and Amare (2016) indicated the negative relationship between increase in *Prosopis* invasion and fodder/feed availability on grazing lands. Studies showed that encroached grazing lands have reduced herbage yield (Moleele *et al*., 2002; Ayana, 2005).

Invasion of *Prosopis* rangelands caused shortage of grazing land for livestock, which resulted in drastic reduction of livestock number as well as products (Senayit *et al*., 2004). *Prosopis* can be a very aggressive invader and it invaded grasslands are transformed to woodland and forests. It replaces native vegetation and takes over rangelands, and leads to complete loss of pasture and rangelands for both domestic and wild ruminants (Khandelwal *et al*., 2015). This is mainly due to reduced land carrying capacity as *Prosopis* trees are displacing desirable grasses that could not withstand the aggressive competition for light, nutrient and moisture (Taye *et al*., 2004).

The invasions of *Prosopis* also compete for and reduce productivity of croplands (Anderson, 2005). The invasion of the plant decreases the size of farm and roots of *Prosopis* makes difficult to plough lands (Niguse and Amare, 2016). The study conducted in Fentale woreda, east Showa zone of Oromia region showed reduction in crop productivity since the invasion of Prosopis takes place in the area (Merga, 2012). Similarly study by Ashenafi (2008) also reported negative impact of *Prosopis* on crop production from high and medium infestation area through competition of agricultural land, wastage of time for clearing and labor cost increment. However, isolated *Prosopis* has also been linked increased crop yields per hectare because it has the ability to improve soils by fixing nitrogen, mulching the soil with its leaves and desalinizing the soils (Felker *et al*., 2001, Kahi and Ngugi, 2009). For example, the report from Afar region showed increase of crop yields by 29% due to presence of *Prosopis juliflora* (Haji and Mohammed, 2013).

Impact on animal production

Recent studies by Ayanu *et al*. (2014) and Haregeweyn *et al*. (2013) have shown the negative relationship between the invasion rate of *Prosopis* and livestock production. The invasion of *Prosopis* has caused considerable decline in livestock production and productivity due to loss of dry season grazing areas by *Prosopis* plants. Palatable indigenous pasture species have all reduced (Admasu, 2008; Mwangi and Swallow, 2005). The total milk loss associated to pasture problems created by *Prosopis* per lactating animal in given lactating period is 10, 1, 5 and 4 liters for cattle, sheep, goat and camel respectively. In addition, the total weight loss associated with pasture problems created by *Prosopis* per animal is 15, 3, 3, and 8 kilograms for cattle, sheep, goats and camel per year respectively (John *et al*., 2014). Similarly, the study by Merga (2012) also reported negative effects of *Prosopis* on livestock production due to the reasons such as encroachment of *Prosopis* to grazing lands and physical injuries to the animals (Zeila, 2011).

Invasion of *Prosopis* caused shortage of grazing lands for livestock, which resulted in drastic reduction of livestock number as well as products (Senayit *et al*., 2004). This is mainly due to encroachments of *Prosopis* to grazing land and cause scarcity of animal food (Niguse and Amare, 2016). *Prosopis* reduces land carrying capacity as *Prosopis* trees are displacing desirable grasses that could not withstand the aggressive competition for light, nutrient and moisture (Taye *et al*., 2004). It also causes overall loss of natural pasture, displacing native trees, reduction in stocking rate, toxicity to livestock and formation of impenetrable thickets (Senayit *et al*., 2004; Taye *et al*., 2004). With the loss of indigenous grasses and other plant species, the main fodder resource for grazers such as cattle, the number and productivity of animals has reduced substantially

(Hamedu, 2014). Yosef *et al*. (2013) using data from the Central Statistical Agency (CSA) of Ethiopia demonstrated that cattle and camel populations in the Amibara zone, which was the study area, declined at a rate of 36% and 20%, respectively, between 1997 and 2011 due to the problems related to *Prosopis* invasion.

Impact on biodiversity

Several studies revealed the loss of biodiversity due to invasion of *Prosopis* are enormous in all parts of the world (Clovis *et al*., 2014; Schachtschneider and February, 2013; Samuel *et al*., 2012). *Prosopis* can suppress the growth of grasses under its canopy and the biodiversity (Niguse and Amare, 2016) by delaying seed germination and reducing plant growth in terms of roots, shoots, leaf area, stem diameter, and plant height (Inderjit *et al*., 2008). It also suppresses biodiversity by computing both resources and natural environment (Niguse and Amare, 2016). Almez (2009**)** from Allideghi Grassland of Ethiopia indicated that *Prosopis* weed occupy new surroundings and often substitute the native plant species, resulting in a serious damage to biodiversity. In India, species richness is estimated to reduce by 63% under *Prosopis* compared to open lands (Kaur *et al*., 2012). Kahi and Ngugi (2009) also found that cover of understory herbaceous plant species in plots invaded by *Prosopis* were 27% less than that in the open areas. Study by Samuel. (2009) pointed out that an increase in the level of *Prosopis* invasion causing rapid decline in the population and diversity of species in the ecosystem. Similarly, the species also reduced the total biodiversity of the arid and semiarid regions by reducing their abundance, distribution, and more importantly by changing the ecosystem function from rangeland to *Prosopis* thicket (Berhanu and Tesfaye, 2006).

Potential uses of *Prosopis julifora*

Converting *Prosopis* into a valuable resource presents an opportunity to the communities living in marginal areas (Pasiecznik, 2007). It is a multipurpose dry land tree or shrubs, and commonly used to improves soil physiochemical and biological properties, generating “fertility islands” or “resource islands” beneath its canopy (Vallejo *et al*., 2012), its pods can be used as a livestock feed and for making human foods; and environmental services provided by nitrogen fixation, shade, shelter, live and dead fencing, erosion control, soil improvement and reclamation are remarkable. Secondary products from this tree includes honey, edible exudates gums, fibres, tannins, foliage for fodder, mulch, biopesticides and medicines, and other uses for wood and pods such as particle board, wood chips for energy generation, pods for ethanol production, galactomannan gums from the seeds and other specialist products (Wise *et al.*, 2012; Oduor and Githiomi, 2013; Haji and Mohammed, 2013; Shimalis and Getachow, 2016).

The result of different study reported that pods from *Prosopis* can be used as source of nutritious, less costly feed ingredient for livestock (Berhanu *et al*., 2013; Chaturvedi and Sahoo, 2013; Stein and Toledo, 2005). These sweet nutritious pods can be used as a livestock feed in different forms, and free ranging animals can eat pods directly from the tree. Alternatively, the pods can be collected and ground to produce course flour which can be included in the animal’s diet. The percentage of the flour in the mix should be kept below 50% in order to avoid digestion disorders among the livestock (Pasiecznik, 2001; Matthijis *et al*., 2014). *Prosopis* pods can also replace concentrate mixture up to 40% in sheep feeding without any adverse effect on nutrient intake and utilization as well as rumen fermentation characteristics (Chaturved and Asahoo, 2013).

Honey from the flowers is of high quality, the gum is similar to gum Arabic, barks and roots are rich in tannin, leaves can be used as mulch and the tree is a nitrogen fixer to the soil. The pods are used to make flour for cakes, biscuits and bread, pop syrup and coffee substitutes (Admasu 2008; Wise *et al.*, 2012). The exudates gums harvested from *Prosopis* trees are important inputs in food, pharmaceutical, chemical and manufacturing industries. Other products of the species include tannins, dyes and medicine (Girma, 2011; Jama and Zeila, 2005; Tegegn, 2008). It also has a potential of being used as potential bio-control agent for invasive weed species, pest and virus (Dhawan, 1995; Singh *et al*., 2011).

In different countries *Prosopis* has been used as a traditional medicine and used as a folk remedy for catarrh, cold, diarrhea, dysentery, excrescences, flu, hoarseness, inflammation, measles, sore throat and in healing of wounds. Decoction prepared from leaf and seed extracts are used in wound healing, as disinfectant and also to treat scurvy (Singh *et al*., 2011). *Prosopis* syrup prepared from ground pods is given to children showing weight deficiency or retardation in motor development, the syrup is believed to increase lactation. Tea made from *Prosopis* is thought to be good for digestive disturbances and skin lesions (Singh *et al*., 2011). It has soothing, astringent, antiseptic, antibacterial and antifungal properties (Shakila and Sukumar, 2014). It has been also used to treat eye problems, open wounds, dermatological ailments and digestive problems by the native tribes of many countries. The flavonoid, patulitrin isolated from its flowers and fruits showed significant activity against lung carcinoma in vivo (Shatiya and Muthuchelian, 2010).

Leaves and pods are to be the richest source of plant metabolite, followed by flower, root and stem. Phytochemical analysis of the extracts revealed the presence of tannins, phenolics, flavonoids, alkaloids, terpenes and steroids in most parts of *Prosopis*. Alkaloids are pharmaceutically significant and are used as analgesic, antimalarial, antiarrythmic, antispasmodic, in the treatment of coughs and pain, in the treatment of gout, and as pupil dilatin (Singh *et al*., 2011). Very high flavonoids content (16%) of *Prosopis* makes it a potential candidate bearing antioxidant and anticancer properties. Tannins and phenols although found in low concentrations, (0.33 and0.66% respectively) can synergize the antioxidant and anticancer potential of flavonoids. Phenols are reported to prevent the platelets from clumping and have the ability to block specific enzymes that cause inflammation. These also act as immune enhancers, anticlotting and hormone modulators. Tannins in the plant cell inhibit hydrolytic enzymes like proteolytic macerating enzymes used by plant pathogens (Ibrahim *et al*., 2013).

Prosopis invasion has also been linked with increased crop yields per hectare because it has the ability to improve soils by fixing nitrogen, mulching the soil with its leaves and desalinizing the soils (Felker *et al*., 2001, Kahi and Ngugi, 2009). For example, the report from Afar region showed increase of crop yields by 29% due to presence of the species (Haji and Mohammed, 2013). It is also an ecological resource as it provides important habitants for plant and animal species, helps in combating drought and desertification (Varshney, 1996). *Prosopis* trees have also provided protection as well as food for wild animals and ameliorated environmental conditions through carbon sequestration (Felker *et al*., 2001; Kaur *et al*., 2012). Felker *et al*. (1990) estimated that *Prosopis juliflora* can sequester carbon biomass extending from 0.65 kg to 1300 Kg per kg/stem which is equivalent to 2-20 tonnes per hectare.

Prosopis wood is hard, burns slowly and has good heating properties, therefore; the charcoal it can produce has good properties and can be easily traded on urban markets although less popular than acacia (Flinton, 2009; Tegegn, 2008). By spreading charcoal and using it as biochar, acidic degraded land can be rehabilitated and yields can be increased. Charcoal improves the physical, biological and chemical properties of the soil by releasing and storing nutrients, increasing the bulk density, improving overall porosity and creating favorable conditions for micro-biological activity. It can be applied in conjunction with farmyard manure and/or soil microbes. The use of *Prosopis* biochar plus manure is known to have brought about a 30-40% increase in cotton yield (Sai Bhaskar Reddy, 2009).

Control methods of *Prosopis julifora* invasion

In areas where *Prosopis* species have already spread over very large areas other *Prosopis* management methods such as preventive and containment are seldom feasible as management options. Control, in conjunction with restorative habitat management, may then be the only realistic recourse. The aim of a control programme is to reduce the abundance and density of infestations, and to keep harmful impacts of an invasion down, as far as possible, to within manageable limits (Gordon and Arne, 2013). In general there are three types of control methods (Mechanical, chemical and biological control strategies), and they are discussed hereunder. Different studies have shown that the invasion of *Prosopis* would be not controlled or reduced by engaging a single management approach. Thus, integrated approaches are warranted to restrict the invasion of this weed by combining more than one option (Samuel *et al*., 2013; Belachew and Tesema, 2015).

Mechanical control methods

Mechanical control options include the physical felling or uprooting of plants, often in combination with burning (Van wilgen *et al*., 2001). Manual and mechanical control methods involve the removal by hand, or with tools, implements, or machines of an infestation's individual invaders. Controlling alien plant invasions manually may include hand-pulling, uprooting, hoeing, felling or cutting back. Such methods can be labour intensive, but in regions where manual labour is readily available and can be hired cheaply manual control is often both effective and economical. Ring-debarking (girdling) may also be effective, albeit only for eliminating woody invaders of species that do not coppice.

Most manual control methods have the added advantage of being wholly target specific. Repeated follow-up control operations are generally required, however, and subsequent rehabilitation measures are essential, as disturbed ground and soil erosion in cleared areas may encourage reinvasion. Manual control alone is seldom entirely successful against large-scale infestations. Mechanical interventions using bulldozers or tractor-drawn ploughs or other machines to clear extensive weed infestations have the obvious drawback of being indiscriminate and of razing non target plant species as well, while at the same time creating conditions that may be ripe for re-invasion. Continuous hand clearing and uprooting of newly growing seedlings from farm lands, grazing lands and around settlements is very important. Mechanical controlling by cutting for charcoal production and fire wood may be effective to lessen the impacts on the native plant species and to reduce its rate of invasion (Abebe, 2012). But due to its high coppicing ability and many sprouting after cutting, cutting will not help to eradicate *Prosopis* in the area unless it is done some distance below the ground. The other most effective but labour and cost intensive mechanical control method was removing of the plant from 10-15cm below the ground and using the land for crop production (Samuel *et al*., 2004).

Chemical control

Chemical control methods, involving the judicious use of approved herbicides, can improve the efficacy of manual and mechanical clearing activities. Applying systemic herbicides to cut tree-stumps or to incisions made in the bark of trees or shrubs (in a procedure known as frilling) will, on spreading through the vascular tissue of treated invaders, eventually kill the targeted trees or shrubs. Basal stem applications and stem injections have the same effect. These applications are very target specific with no discernable non target impacts (Gordon and Arne, 2013).

Larger trees and shrubs are killed by cutting the stem at ground level and spraying or painting the freshly cut stumps with suitable herbicide. Herbicides like Round up, 2-4, D, Glenside Kerosene and diesel oil are used. Foliar sprays of herbicides such as glyphosate are widely used to control the seedlings of woody invaders. Herbicidal sprays, applied using portable 'pack' sprayers, offer a fast and effective means of control, yielding rapid results. Where chemical treatments can be administered topically to individual plants, the risks of inflicting collateral damage, detrimental impacts on non-target species, always a danger with herbicides can be minimized. Many herbicides are non-selective in their action, so particular care has to be taken over their application (Gordon and Arne, 2013).

Effective herbicides are registered for use against weed but chemical control requires repeated, regular follow-up treatments (Lorraine and Lin, 2015). Generally, Triclopyr + picloram @ 1 L/60 L diesel can be used to effectively control Prosopis plants up to five cm in diameter and wet stem thoroughly from ground to 30 cm height. Triclopyr + picloram @ 1 L/60 L diesel can control *Prosopis* by cutting stem close to ground level and treating immediately. *Prosopis* seedlings and plants up to 1.5 m tall can be controlled by high volume (overall spray) of triclopyr + picloram e.g. Grazon DS Extra (DAFF Queensland, 2013).

The study conducted by Shanwad et al. (2015) on effectiveness of herbicide application showed that Mera-71 @ 40 gm/ltr followed by 2,4-D @10 gm/ltr found to be effective than the paraquat @ 30 ml/ltr and diuron @ 5 gm/ltr across all stem thickness Sizes. The study also showed that combination of herbicides (Mera-71 and 2, 4- D) controls the *Prosopis juliflora* growth better than the individual application. Mera-71 (Glyphosate and 2, 4- D) were almost twice as effective as paraquat and 3 times as effective as Diuron (Shanwad *et al*., 2015).

Biological control

Biological control (biocontrol) has in recent decades gained acceptance in many countries as the most cost-effective and reliable means of managing large infestations of invasive alien plant species. Biocontrol involves the deliberate, closely-monitored introduction of one or more species of highly specialized alien organisms that hail from the original home range of the invading plant species, and which physiologically are adapted to feeding exclusively on or attacking exclusively plants of that species (Gordon and Arne, 2013).

The introduced host-specific organisms are generally insects, mites, or pathogens (mainly fungi). These are organisms that in the homelands of the plants keep their growth in check. And it is in the absence of these natural enemies that the plants, in their adoptive homes, where they encounter no such enemies, are able to explode into abundance and become invasive. Control organisms of more than one species may be introduced, each for its role in attacking a different part of the targeted invasive species. Biocontrol does not eradicate the alien plant invader, but rather weakens its competitiveness with native plant species, suppressing its density and environmental impacts, so allowing the native vegetation to recover (Gordon and Arne, 2013).

Predators or pathogens are used to control the *Prosopis* reproduction. Sudanese researchers found some predator insects that attack the leaves that lead to deterioration of the tree canopy. In Australia four species of insects have been introduced as biological control agents against mesquite: The *Algarobius bottimeri* and *Algarobius Prosopis juliflora* (The larvae of these beetles destroy mesquite seeds in mature pods both in the trees and on the ground), the *Prosopidopsylla flava* (a sap-sucking psyllid that causes dieback) and *Evippe* spp. (a leaf-tying moth that causes defoliation). Nevertheless, this is a very slow operation to eradicate the tree (DAFF Queensland, 2013).

Four biological control agents have been released in Australia: *Algarobius bottimeri* and *A. Prosopis* (seed-feeding bruchids), *Evippe* species (a leaf-tying moth) and *Prosopidopsylla flava* (a sap sucker) (van Klinken *et al*., 2003; van Klinken 2012). Two have established widely (*A. Prosopis*, *Evippe* species), and the latter has had noticeable impacts on *Prosopis* populations through reducing long-term growth rates (van Klinken, 2012). Biological control in Australia has been more successful than in other places like South Africa and the benefit-to-cost ratios are positive (0.5), with expectations to increase in the future (Page and Lacey, 2006). The release of more agents is recommended to further improve control (van Klinken *et al*., 2003; van Klinken 2012).

Control by Utilization

Conventional *Prosopis* control methods particularly by mechanical and chemical means, have been expensive and ineffective (McConnachie *et al*., 2012; Sato, 2013). As a result the strategies that aim to minimize costs and maximize economic benefits are being sought in several developing countries. Therefore; it could be argued that utilization of *Prosopis* is the best option to control invasion of many invaded areas (Tessema, 2012; Wakie *et al*., 2012). This phrase was first coined by Tessema (2012) to explain the economic exploitation of invasive species as a means of harnessing their economic potentials for meeting basic human needs and at the same time control its spread and possibly eradicate them. These utilization schemes are promoted in developing countries because they create new income opportunities for the affected communities, while positively contributing towards the control and management of the invasive species. Biological and mechanical controlling approaches, which incur higher costs, are the least preferred options in most developing countries (Shackleton *et al*., 2014).

Existing *Prosopis* eradication and utilization practices in Ethiopia include conversion of invaded lands into irrigated agriculture, charcoal production, and flour production (Admasu, 2008; Wakie *et al*., 2012). Non-governmental organizations (NGOs) working in Afar have in the past formed cooperatives that produced and sold *Prosopis* charcoal and flour produced from its seed pods (Admasu, 2008). *Prosopis* charcoal, grown and produced in Afar, is currently distributed and sold in major Ethiopian cities including Addis Ababa and Mekelle (Bekele and Girmay, 2013). Flour, which is used as animal feed, is produced by crushing and milling seed pods.

Study by Wakie *et al.* (2016) and Stille *et al.* (2011) showed that controlling the spread of the *Prosopis* through its utilization can be a cost-effective management strategy under the right environmental setting. Managing *Prosopis* infested sites for charcoal production purposes and conversion of *Prosopis* invaded lands into irrigated agriculture is economically feasible (Wakie *et al*., 2016). Studies conducted in India also suggest that making charcoal from *Prosopis* wood is profitable (Gupta, 1985; Stille *et al*., 2011). Charcoal policies (e.g., production, transportation) that seem to be lacking in the country (Bekele and Girmay, 2013) also need to be adjusted to account for the sustainable growth of the charcoal business in the region.

Different study showed that making flour from *Prosopis* pods can also be used to prevent new invasions by destroying viable seeds. However, the business was not economically viable under the current management practices implemented in Ethiopia. The reasons include high initial investment costs, high pod processing costs (e.g., drying, crushing), and poor marketing practices (Wakie *et al*., 2016). In Kenya, for instance, the value of *Prosopis* flour was highly improved by supplementing it with antiemetic medicines, converting it into feed blocks, and marketing the product as best animal feed that controls worms and increases livestock productivity (Syomiti *et al*., 2015). Flour enterprises in Ethiopia need support from research organizations, especially on nutritional values, chemical compositions, and toxicity levels of *Prosopis* pods. Subsidizing flour producers should also be considered as contribution towards the control and eradication of this highly invasive plant.

Some general recommendations arise from the present review:

- A well-planned programme that encourage the participation of all stake holders from national to district level including universities, research centers, individual researchers, government and non-governmental organizations as well as the local traditional institutions should work collaboratively so as to develop strategies for controlling further distribution or achieve eradication of this weed;
- Adoption of integrated controlling methods which can provide a synergistic effect. In this case there should be a long-term and effective plan that transforming the area which previously occupied by *Prosopis* in to cropping land or other business environment;
- Creating public awareness especially in pastoral and agro-pastoral areas about the effect of *Prosopis* on agricultural productivity, human health, and ecosystem. In line with this cost effective and simple controlling methods which can be accomplished by these groups should be identified so as to reduce its future life span. Research findings should be presented in a language that can be understood by all stake holders;
- There should be extension service which can create strong network with society for disseminating new technologies and research findings in local languages. This extension

service can be facilitated by using the national and local television, radio programs, newsletter, newspaper, brushers, and pamphlets.

CONCLUSIONS

Prosopis used for charcoal production, house/fence construction, livestock feed, food, soil conservation, erosion control, fixation of nitrogen in the soil, dyes, traditional medicine, shades, medicines, gums, apiculture, control invasive weed and other important functions. On the other hand, the species is among the most widespread damaging alien plant species in various environments including crop lands, rangelands, road sides, forests, watersheds and other economically important ecosystems; and there is also much potential for species to spread further. The disadvantages and costs of *Prosopis* for local livelihoods, rangeland health and biodiversity, and for the national economy due to reduced livestock production, outweigh the benefits. The detrimental effects on the environment and human livelihoods are escalating rapidly from time to time, and there is an urgent need to devise more effective management approaches to drastically reduce adverse impacts and enhance benefits.

By using its potential beneficial effects as opportunity there is a possibility to eradicate this weed through time. This can be achieved by creating job opportunity for job seekers which ensuring the proper removal of the tree for different purposes. However, there must be initial support from the government and nongovernmental organizations for those groups so as to ensure the effectiveness of eradication by utilization

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