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Critical Review Of *Prosopis Juliflora* Species In Turkana County, Kenya: Current Status For Informed Policy Decision And Management Of The Species

Akwee, P. E.

Department of Biological and Physical Sciences, Turkana University College, Lodwar

Nambafu, G. N.

Department of Biological and Physical Sciences, Turkana University College, Lodwar

Abstract: ***Prosopis juliflora is among one of the world's most invasive alien species that is widely spreading in Kenya natural grazing lands due to its adaptive physiological characteristics. The species came from south Africa with the intention of benefiting the people living in the Arid and Semi-Arid Lands (ASAL), which ironically resulted in more harm than good. Turkana and Baringo are heavily hit counties whose people are suffering from the continuous expansion of land under Prosopis. Their speedy growth, development and colonization of an area are driven by the climate, existence of large herds of livestock, government policies and topography. To completely eradicate the species from agricultural land, it calls for an integrated approach that will bring together mechanical, chemical and biological methods of controlling Prosopis. To that extent, the Kenya government should enact appropriate policies governing its spread and detach Prosopis invested land from gazette government forest.***

Keywords: ASALs, Policies, Integrated Approaches, Prosopis and Turkana County

I. PROSOPIS SPECIES AND THEIR ORIGIN

Prosopis is a xerophyte belonging to the genus of flowering plants in the family of Fabaceae species and are native to many nations (Patnaik et al., 2017; Hussain et al., 2020). The generic names were instigated from the Greek language and later adopted in Latin, which means 'burdock' (Rasanen & Lindstrom, 2003; Nabhan, 2018). There are more than 45 different species of prosopis found grown in subtropical and tropical regions of Africa, America and South & Western Asia (Zachariades et al., 2011). The dominant species are *Prosopis glandulosa*, *P. laevigata*, *P. Velutina* common in South America and Mexico (Pasiecznik et al., 2004), *P. abbreviate*, *P. alba*, *P. chilensis*, *P. juliflora*, *P. pallida*, *P. strombulifera*, *P. calidenia* common in Neotropics, Argentina, Bolivia and Paraguay, Brazil (Pasiecznik et al., 2004), P. Africana common in Nigeria (Ataguba et al., 2015; Dau & Chenge, 2016), *P. cineraria*, *P. farcta*, *P. koelziana* extending from India to the Arabian Penisnsula (Baibout et al., 2022; Hughes et al., 2022).

The species are deep rooted and thrives well in arid sandy soils (Singh, 2022). The mature Prosopis have hard, dense and durable wood as well as pods (fruits) high in sugar (Wakie et al., 2016; Nabhan, 2018). The presence of sugar in the species has been associated with the wide spread of malaria in prosopis invested areas as the trees enhance the transmission of mosquito's plasmodium (Muller et al., 2017). Prosopis species have also been found to contain tannin, 5-hydroxytryptamine, tryptamine, apigenin, l-arabinose, isorhamnetin-3-diglucoside and quercetin (Prabha et al., 2014; Afifi et al., 2018; Singh & Pareek, 2023) . Some species like *P. africana* and *P. velutina* are known for gum production (Pasiecznik et al., 2004; Wakie et al., 2012). *P. Juliflora* mainly produce two products namely 5-HTP and tryptamine (Prabha et al., 2014; Sharifi-Rad et al., 2019)).

Prosopis juliflora, also known as Mathenge tree in Kenya, is a native of Mexico, Carribian and South America which is invasive (Pasiecznik et al., 2001; Masakha, 2013; Ilukor et al., 2014; Okumu, 2019). The trees can grow to a height of 12 meters and drunk diameter of 1.2 meters (Hughes et al., 2022).

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The tree has deciduous, light green leaves with about 12 to 20 leaflets (Pasiecznik, 2001; Shaheen et al., 2020). The pods that result from fragrant golden yellow flowers are about 30cm long, with each pod containing a maximum of 30 seeds (Maundu et al., 2019; Pasiecznik, 2001; Hughes et al., 2022). The seeds are mostly propagated by animals (mostly camels, cattle and sheep) who feed on them spread through droppings (Masakha,2013; Okumu, 2019; Singh, 2022). The species contains thorns in pairs at the nodes while its roots are able to grow to a depth of 53m in search of water (Gallaher & Merlin, 2010).

II. INTRODUCTION AND SPREAD OF PROSOPIS TO KENYA

In Sub Sahara African countries including Kenya, about 40 species of Prosopis species have been reported. The widely known and mostly reported Prosopis species: *Prosopis juliflora, Prosopis chilensis and Prosopis pallida* with *Prosopis juliflora* being the most invasive (Catterson Thomas, 2003). In Africa, Prosopis was first reported in Senegal 1822, and then later to South Africa and Egypt in 1880 and 1900, respectively (Pasiecznik et al., 2001; Choge et al., 2007; Wudad & Abdulahi, 2021). In Kenya, the *P. juliflora* is an invasive species that was introduced in the arid and semi-arid areas (Zeila, 2011; Nadio, 2020). Countries like Hawaii and all states in Australia have branded *P. juliflora* a noxious weed.

P. juliflora was introduced in Kenya in the early 1970s in Mombasa to rehabilitate quarry and (Baringo region) in the 80s from South Africa as an initiative to combat desertification, provide firewood to community, shade, construction materials and fodder for the livestock (Pasiecznik et al., 2001; Choge et al., 2007; Tilahun et al., 2016; Mwania, 2017). This plant was introduced by the Government of Kenya under the stewardship of the National Irrigation Board (NIB), Kenya Forestry Research Institute (KEFRI) in collaboration with the government of Finland to restore the Njemps plain, right from Ngambo to Loboi then later covered the entire Marigat Subcounty (Kahi, 2004, Choge et al., 2007; Maundu et al., 2009; Oduor & Githiomi, 2013; Odhiambo, 2016). Indeed, it transformed the plain into a greener and densely tree-shielded landscape combating firewood & fodder shortage, soil erosion, and sandstorms (Oduor & Githiomi, 2013; Wakie et al., 2016; Singh, 2022).

The disguised blessing became a curse as the tree spread rapidly across the region, causing more harm than good (Choge et al., 2007). The rate of spread was alarming as the tree could cover about 500 – 1,300 hectares per year (Gichua, 2014). By 2009, *P. juliflora* had spread entirely in all arid and semi-arid areas of East Africa (Maundu et al., 2009), Kenya included (Fig 1).

In Kenya, *P. juliflora* can be found in the East and North East of the country, as well as in parts of the Rift Valley and the coastal region (Mwangi & Swallow, 2005; Maundu et al., 2009). Their growth and spread in arid and semi-arid areas is supported by waters from lakes and river systems like the Lake Baringo, Tana River and Turkwel rivers, thus posing a major threat to these water ecosystems (Maundu et al., 2009; Mworia et al., 2011; Nadio et al., 2020; Hussain et al., 2021).

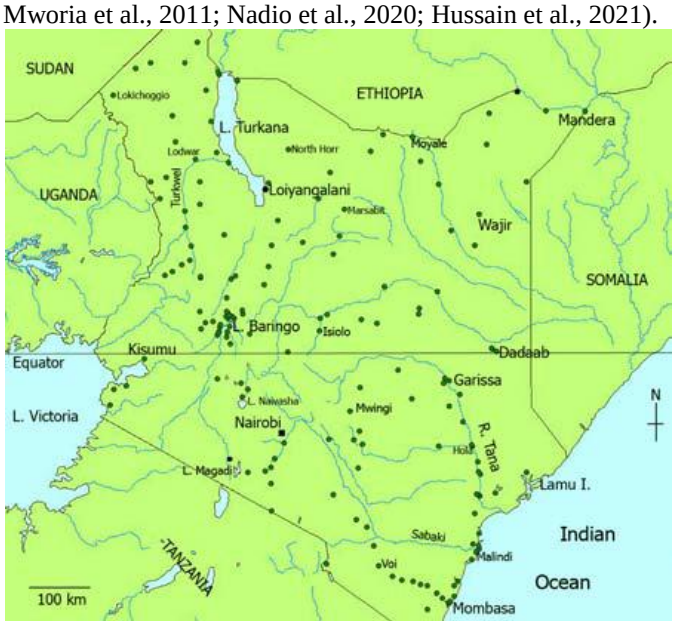

Figure 1: Distribution of Prosopis juliflora in Kenya in 2009; image source (Maundu et al., 2009)

The densest thicket of Prosopis is currently found in Baringo, Taita-Taveta and Turkana Counties thus colonizing most of the grazing areas, ending up barring the growth of other plants (Koech et al., 2021; Choge et al., 2022). Arid and semi-arid areas account for 80% of the Kenya's land mass of which Prosopis have occupaid the entire 50% land mass (Maundu et al., 2009; Mbaabu et al., 2019). It is estimated that Prosopis has colonized over 1.5 million hectares of Kenya's land mass (Koech et al., 2020). In 2016, the Prosopis had occupied more than 18,500 hectares in Baringo county (Mbaabu et al., 2019; Eschen et al., 2021). In Turkana County, the Prosopis plant invaded many areas, among them Katilu, Letea, Lokangai, Songoti, Lotubai, Kalokol, Loriu, Naman, Kerio and Turkwell wards (Choge et al., 2007; Nadio et al., 2020). Currently, the county is leading in the area covered by Prosopis across the country, estimated to be about 3,300 square kilometers (Omungo, 2018; Mumina & Bourne, 2020). This has happened after the introduction of the species in 1979 by the Government of Kenya (GoK) alongside Norwegian Agency for Development Cooperation (NORAD) through a Rehabilitation Project by the Turkana district (Choge et al 2002; Nadio et al., 2020). The development agencies provided an avenue for the spread of the species up to the refugee camps in Kakuma and Lokichoggio since the trees could withstand constant cuttings (Maundu et al., 2009). The tree is now all over Turkana County and can be seen along the highways, right from Kainuk to Lokichogio.

Given the wide spread of Prosopis, rapid climate change effects and minimal efforts to control the plant, it may soon hit the heart of the Kenya economy, particularly crop lands, range lands and national parks and reserves. Thus, the government needs to provide technical know how and information on the control of the species, since manual removal of the species may be too expensive for the country.

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III. ECOLOGICAL DRIVERS OF PROSOPIS INVASION IN DRYLAND AREAS

History and satellite images (Fig. 2) show that Prosopis were dominant near water bodies and along the drainage lines/ riverine in the dry areas of Kenya (Mworia et al., 2011; Nadio et al., 2020; Hussain et al., 2021; Kihungu, 2022). Given the poor drainage systems of the dryland soils, there has been lots of surface runoff during heavy down pour aiding to the thriving of Prosopis (Karuku, 2018). For instance, seasonally flooded areas like Lotikipi aid in the dispersal of seeds and enhance the germination of Prosopis species (Maundu et al., 2009). During EL Nino rains in 1997, it was revealed that Prosopis inhabited Kenya's arid and semi-arid lands very quickly while getting favor from the high humidity and temperatures of the place (Opiyo, 2014; Becker et al., 2018). This was denoted by the outcry from the community members, immediately after the rains (Omungo, 2018).

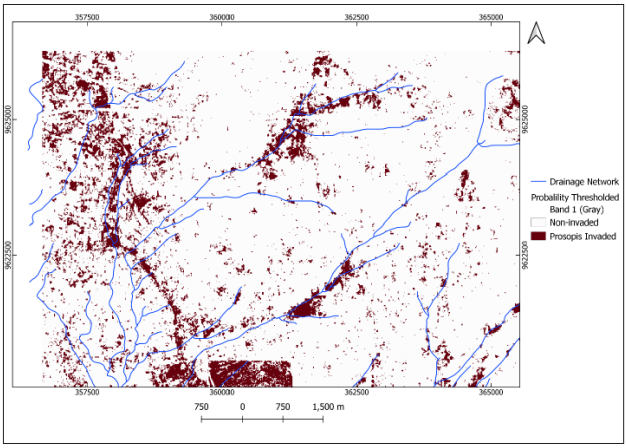

Figure 2: Drainage lines invaded by Prosopis in Taita Taveta County; Image source (Kihungu, 2022)

People in Arid and semi-arid areas are pastoralists who are known for keeping large numbers of livestock (Huho & Omar, 2020, Mbaabu et al., 2020). Due to limited feeds the animals move from one point to the other. The sweet pods and leaves encourage the animals to feed on them and in the process, they disperse the seeds whenever they go through feces (Alvarez et al., 2017). Overgrazing has led to degraded grasslands (Doran et al., 1979; Witt & Luke, 2017; Eschen et al., 2021), thus creating a better environment for the invasive Prosopis species thus tumbling accessibility, abundance and quality of feeds (Kassahun et al., 2005; Linders et al., 2019). Prosopis are fast growing species with strong coppicing ability which enables it to colonize an area within the shortest time possible (Mbaabu et al., 2020).

Prosopis thrives well in all types of soils (Ng et al., 2018). The nature of the soils in the drylands have contributed, to a greater extent, to the Prosopis inversion (Throop & Archer, 2008; Eshete et al., 2020). Most of the soils are saline in nature due to high evaporation rates witnessed in the region, as well as highly alkaline in nature (Mwangi & Swallow 2005; Narain, 2008; Sharma & Singh, 2019). Prosopis, as opposed to legumes and other crops, can tolerate salinity levels of up to 32,000 mg/L NaCl (Velarde et al., 2003). Alternatively, they do well in soil with pH above 10 (Ewens et al., 2022). The nutrient-rich soils are said to support herbaceous vegetation like Prosopis (Kahi, 2004). Prosopis seed germination, survival and life expectancy can be positively impacted by high nutrient availability (Alvarez et al., 2017; de Souza Nascimento et al., 2020).

Prosopis can grow in areas receiving a wide range of rainfall ranging from 50mm to 1500mm per annum (El-Keblawy et al., 2015). During severe droughts, the tree remains green with all its leaves intact and can bear fruit (Shiferaw et al., 2004; Damasceno et al., 2017). High rainfall rates may render the soil ineffective as it becomes excessively humid and hinder Prosopis growth (Shiferaw et al., 2004). The plant adapts well in dry and hot areas with an average temperature of up 40^{o}C (El-Keblawy & Gairola, 2017; Hussain et al., 2020; Slate et al., 2020). Studies by Eschen et al., 2021 and Bogale & Tolossa 2021, shows that climate change may worsen the problem by increasing the invasion rates and extension of coverage areas due to changing rainfall patterns thus further decrease in fodder.

IV. MECHANICAL CONTROL AND INTEGRATED APPROACHES TO MANAGEMENT OF THE SPECIES

Mechanical methods are common practices used for controlling Prosopis, in both developed and developing nations (Wakie et al., 2016). This method can be financially costly when applied in a huge area, heavily invaded with Prosopis species. For instance, studies show that at one point South Africa used approximately \$2800 ha^{-1} to partially remove *P. juliflora* (Shackleton et al., 2014). Prosopis plants can be removed by using hands i.e., cutting, pulling, digging and mechanical uprooting (Tu et al., 2001; Shibru, 2015; Kool et al., 2019; Eschen et al., 2023). These methods are being used across Turkana County, especially Turkana west sub-county although monitoring and maintenance of the area has been a problem. Developed nations depend mostly on machines and have resolved more to bulldozer pulling, chain pulling, stick racking and blade ploughing (Vitelli & Pitt, 2006; Gallaher & Merlin, 2010; Northern Territory Government, 2015). On the other hand, spraying of species with hot salty water and smearing coal can be practiced. Farmers also use fires to burn plants to reduce their spread (Shanwad et al., 2015). Burning helps in vegetation reduction and killing of seeds that are on the Prosopis plant and those that have fallen on the ground (Campbell & Setter, 2002; DiTomaso et al., 2006; Eschen et al., 2023). There are major disadvantages associated with use of fire like killing of non-targeted plants species, wildfires risks and non-uniform destruction of species (Kool et al. 2019).

Besides, the application of herbicides (chemical treatment) has shown tremendous results in the control of Prosopis (Sakthieswaran & Sophia, 2020; Balcha, 2022). The use of keroscene, glyphosate, diuron, paraquat, coaltar, 2,4-D amine and ester either in combination or individual chemicals have reduced both growth and development of Prosopis (Shanwad et al., 2015; Kaur et al., 2022). For efficient and effective results, the choice of chemical, application method, time and dosage are to be considered (Ansley et al., 2004; Vitelli & Pitt, 2006; Getachew et al., 2012; Shanwad et al.,

2015). The waxy layer on the outer part of Prosopis species, coupled with thick bark, small leaves and woody stems, may inhibit the penetration of chemicals, thus more analysis is required before arriving at the best combination or individual herbicide (Bovey, 2016; Nath et al., 2020;). Alternatively, some chemicals work well on the freshly cut stamp of mature prosopis which aid in killing the phloem and xylem prohibiting re-growth of the species (Kool & Nzumira, 2015).

Integrated control of Prosopis species can be done biologically through the introduction of seed feeding insects (Zachariades et al., 2011). Many studies have attributed the invasion of Prosopis to annual production of hefty numbers of seeds, thus a mechanism to destroy the seeds may be vital to prevent its growth and spread (Shiferaw et al., 2004; Shackleton et al. 2014). Bruchids especially, *Algarobius prosopis* (LeConte) and *Algarobius bottimeri* kingsolver have been found to destroy massive seeds in North America and South Africa (Zimmermann, 1991; Palmer et al., 2010; Zachariades et al., 2011; Cullen et al., 2012). These insect (beetles) species have also been seen effective in Australia alongside *Prosopidopsylla flava* -a sap-sucking psyllid that results in dieback, and *Evippe spp*.- a leaf-tying moth that results to defoliation (van Klinken et al.,, 2003; Gallaher & Merlin, 2012; Zachariades et al., 2011). There is also a need in have agents that can destroy the plant at its vegetative stage or those that can prevent pod setting and seed maturation (Kleinjan et al., 2021). An integrated approach that calls for a combination of either mechanical and biological or mechanical and chemical may work tremendously well. The use of three methods in combination may give better results in case the chemical used will have no adverse effects on the insects or organisms used.

V. CONCLUSIONS

There is evidence that Prosopis has taken over massive land in Turkana County. If proper measures are not taken, there is a possibility of the whole county being invaded, with Prosopis leading to downgraded livelihood among the communities. It also calls for combined efforts among different players working in government institutions, non-governmental organizations (NGOs) and private sectors. Prosopis invasion does not only touch on environmental matters but a wide spectrum of disciplines ranging from agriculture, survey, wildlife, forestry, livestock and climate change.

VI. RECOMMENDATIONS FOR POLICY MAKERS

There is great need for policy makers and researchers to disseminate scientific findings in *Prosopis juliflora* to the public and local communities affected by this invasive species.

The local communities living in the region need to be trained on growth and dependency on different sources of livestock feeds besides *Prosopis* to minimize spread via animals.

There must be a policy that controls the movement of animals; for instance, animals from heavily invaded areas are denied access in sparse or non-invaded areas. This may be achieved through demarcation and mapping out these regions.

For a long time, there was no policy guiding the management of Prosopis but as from 30th December 2008, the minister for agriculture in Gazette Notice no. 184 on the Suppression of Noxious Weeds Act (Cap. 325) published in the Kenya Gazette of 9th January, 2009 by government of Kenya (GoK, 2009), declared *Prosopies juliflora* as a noxious weed. The ban affected the Prosopis prone areas, as the communities could not use the species in what is referred as utility control. Thus, the government need to separate the invasive trees/ forest cover from other useful trees for informed decision making on their control. Additionally, the communities should be allowed to do massive falling of Prosopis for charcoal, poles on commercial purpose.

There is need of concerted efforts from all stakeholders including both levels of government (County government and National government), Non-governmental organizations (NGOs), research institutions, academia community, civil societies and the local community to address its control and management of the lands with *Prosopis* species. Therefore, this calls for appropriate policies, funded research to carry out demand driven action researches and strengthening capacity building.

REFERENCES

[1] Afifi, H. S. A., & Al-rub, I. A. (2018). Prosopis cineraria as an unconventional legumes, nutrition and health benefits. In Legume seed nutraceutical research. IntechOpen.
[2] Alvarez, M., Leparmarai, P., Heller, G., & Becker, M. (2017). Recovery and germination of Prosopis juliflora (Sw.) DC seeds after ingestion by goats and cattle. Arid land research and management, 31(1), 71-80.
[3] Ansley, R. J., Pinchak, W. E., Teague, W. R., Kramp, B. A., Jones, D. L., & Jacoby, P. W. (2004). Long-term grass yields following chemical control of honey mesquite. Journal of Range Management, 57(1), 49-57.
[4] Ataguba, C. O., Enwelu, C., Aderibigbe, W., & Okiwe, E. O. (2015). A comparative study of some mechanical properties of gmelina arborea, parkia biglobosa and prosopis africana timbers for structural use. International Journal of Technical Research and Applications, 3(3), 320-324.
[5] Baibout, M., Corcket, E., Kothari, S. L., & Fievet, V. (2022). Ecosystem services provided by Prosopis cineraria (L.) Druce in the drylands of Southern and Western Asia. Botany Letters, 169(1), 30-42.
[6] Balcha, L. D. (2022). Prosopis juliflora Distribution, Impacts, and Control Methods Available in Ethiopia. Int. J. Nat. Resour. Ecol. Manag, 7, 132-144.
[7] Becker, M., Alvarez, M., Heller, G., Leparmarai, P., Maina, D., Malombe, I., ... & Vehrs, H. (2018). Land-use changes and the invasion dynamics of shrubs in Baringo. In Resilience and Collapse in African Savannahs (pp. 111-129). Routledge.
[8] Bogale, G. A., & Tolossa, T. T. (2021). Climate change intensification impacts and challenges of invasive species

and adaptation measures in Eastern Ethiopia. Sustainable Environment, 7(1), 1875555.
[9] Bovey, R. W. (2016). Mesquite: history, growth, biology, uses, and management. Texas A&M University Press.
[10] Choge, S. K., Ngunjiri, F. D., Kuria, M. N., Busaka, E. A., & Muthondeki, J. K. (2002). The status and impact of Prosopis spp in Kenya.
[11] Choge, S. K., Pasiecznik, N. M., Harvey, M., Wright, J., Awan, S. Z., & Harris, P. J. C. (2007). Prosopis pods as human food, with special reference to Kenya. Water Sa, 33(3), 419-424.
[12] Choge, S., Mbaabu, P. R., & Muturi, G. M. (2022). Management and control of the invasive Prosopis juliflora tree species in Africa with a focus on Kenya. In Prosopis as a Heat Tolerant Nitrogen Fixing Desert Food Legume (pp. 67-81). Academic Press.
[13] Cullen, J., Julien, M., & McFadyen, R. (2012). Biological control of weeds in Australia. Csiro Publishing.
[14] Damasceno, G. A. D. B., Ferrari, M., & Giordani, R. B. (2017). Prosopis juliflora (SW) DC, an invasive specie at the Brazilian Caatinga: phytochemical, pharmacological, toxicological and technological overview. Phytochemistry reviews, 16, 309-331.
[15] Dau, J. H., & Chenge, B. I. (2016). Growth space requirements models for Prosopis africana (Guill & Perr) Taub tree species in Makurdi, Nigeria. European Journal of Biological Research, 6(3), 209-217.
[16] de Souza Nascimento, C. E., da Silva, C. A. D., Leal, I. R., de Souza Tavares, W., Serrão, J. E., Zanuncio, J. C., & Tabarelli, M. (2020). Seed germination and early seedling survival of the invasive species Prosopis juliflora (Fabaceae) depend on habitat and seed dispersal mode in the Caatinga dry forest. PeerJ, 8, e9607.
[17] DiTomaso, J. M., Brooks, M. L., Allen, E. B., Minnich, R., Rice, P. M., & Kyser, G. B. (2006). Control of invasive weeds with prescribed burning. Weed technology, 20(2), 535-548.
[18] Doran, M. H., Low, A. R., & Kemp, R. L. (1979). Cattle as a store of wealth in Swaziland: implications for livestock development and overgrazing in Eastern and Southern Africa. American Journal of Agricultural Economics, 61(1), 41-47.
[19] El-Keblawy, A., & Gairola, S. (2017). Dormancy regulating chemicals alleviate innate seed dormancy and promote germination of desert annuals. Journal of Plant Growth Regulation, 36, 300-311.
[20] El-Keblawy, A., Abdelfattah, M. A., & Khedr, A. H. A. (2015). Relationships between landforms, soil characteristics and dominant xerophytes in the hyper-arid northern United Arab Emirates. Journal of Arid Environments, 117, 28-36.
[21] Eschen, R., Bekele, K., Jumanne, Y., Kibet, S., Makale, F., Mbwambo, J. R., ... & Schaffner, U. (2023). Experimental prosopis management practices and grassland restoration in three Eastern African countries. CABI Agriculture and Bioscience, 4(1), 21.
[22] Eschen, R., Bekele, K., Mbaabu, P. R., Kilawe, C. J., & Eckert, S. (2021). Prosopis juliflora management and grassland restoration in Baringo County, Kenya: Opportunities for soil carbon sequestration and local livelihoods. Journal of applied ecology, 58(6), 1302-1313.
[23] Eshete, A., Treydte, A. C., Hailemariam, M., Solomon, N., Dejene, T., Yilma, Z., & Birhane, E. (2020). Variations in soil properties and native woody plant species abundance under Prosopis juliflora invasion in Afar grazing lands, Ethiopia. Ecological Processes, 9, 1-12.
[24] Ewens, M., Felker, P., & Paterson, A. (2022). Genetic improvement in Prosopis. In Prosopis as a Heat Tolerant Nitrogen Fixing Desert Food Legume (pp. 139-156). Academic Press.
[25] Gallaher, T., & Merlin, M. (2010). Biology and impacts of Pacific island invasive species. 6. Prosopis pallida and Prosopis juliflora (Algarroba, Mesquite, Kiawe) (Fabaceae). Pacific Science, 64(4), 489-526.
[26] Getachew, S., Demissew, S., & Woldemariam, T. (2012). Allelopathic effects of the invasive Prosopis juliflora (Sw.) DC. on selected native plant species in Middle Awash, Southern Afar Rift of Ethiopia. Management of Biological Invasions, 3(2), 105-114.
[27] Gichua, M. K. (2014). Impacts of Prosopis juliflora Linnaeus emend. Burkart on aspects of biodiversity and selected habitat conditions in Baringo Kenya (Doctoral dissertation).
[28] Government of Kenya (GoK), (2009). The suppression of Noxious weeds Act CAP 325. Gazette Notice No 184. Vol cxi-No two pages 50, 9th January 2009 Accessed at Kenyalaw.org.
[29] Huho, J. M., & Omar, M. H. (2020). Prosopis juliflora in Asals of Kenya: A friend or a foe plant. International Journal of Scientific and Research Publications, 10(3), 9968.
[30] Hussain, M. I., Shackleton, R. T., El-Keblawy, A., Del Mar Trigo Pérez, M., & González, L. (2020). Invasive Mesquite (Prosopis juliflora), an allergy and health challenge. Plants, 9(2), 141.
[31] Hussain, M. I., Shackleton, R., El-Keblawy, A., González, L., & Trigo, M. M. (2021). Impact of the invasive Prosopis juliflora on terrestrial ecosystems. Sustainable Agriculture Reviews 52, 223-278.
[32] Ilukor, J., Birner, R., Tilahun, M., & Getu, S. (2014). 4. A social-economic assessment of the impact of Prosopis juliflora invasion and participative management ap-proaches in the Afar Region, Ethiopia. Managing Prosopis Juliflora for better (agro-) pastoral Livelihoods in the Horn of Africa, 30.
[33] Kahi, H. C. (2004). The Effects of Prosopis julifora (DC) Hyne and Acacia tortilis (Forsk) Trees on Understorey Plant Species and Soil Properties on Njemps Flats, Baringo District, Kenya (Doctoral dissertation).
[34] Karuku, G. N. (2018). Soil and water conservation measures and challenges in Kenya; A review.
[35] Kassahun, Z., Yohannes, L., & Olani, N. (2005). Prosopis juliflora: potentials and problems. Arem, 6, 1-9.
[36] Kaur, G., Singh, N., & Rajor, A. (2022). RSM-CCD optimized Prosopis juliflora activated carbon for the Adsorptive uptake of Ofloxacin and disposal studies. Environmental Technology & Innovation, 25, 102176.

[37] Kihungu, R. N. (2022). Mapping Prosopis Juliflora Aboveground Biomass Using Remote Sensing in Taveta Sub-county, Kenya (Doctoral dissertation, university of nairobi).
[38] Kleinjan, C. A., Hoffmann, J. H., Heystek, F., Ivey, P., & Kistensamy, Y. (2021). Developments and prospects for biological control of Prosopis (Leguminosae) in South Africa. African Entomology, 29(3), 859-874.
[39] Koech, G., Sola, P., Wanjira, E. O., Kirimi, M., Rotich, H., & Njenga, M. (2021). Charcoal production from invasive Prosopis juliflora in Baringo County, Kenya (Vol. 4). CIFOR.
[40] Koech, G., Wanjira, E. O., Kirimi, M., Siko, I., Sola, P., Bourne, M., ... & Njenga, M. (2020). Utilizing mathenge (Prosopis juliflora) for charcoal: The other side of an invasive species. Miti Magazine.
[41] Kool, M., Mohamed, Y. A., & Nzumira, H. (2019). Controlling and/or using Prosopis juliflora in Spate Irrigation Systems. Managing Prosopis Juliflora for better (agro-) pastoral Livelihoods in the Horn of Africa, 73.
[42] Lagat A. (July 6, 2023). Kenya's lifting of a logging ban has reignited a row over a "corrupt" agency
[43] Linders, T. E. W., Schaffner, U., Eschen, R., Abebe, A., Choge, S. K., Nigatu, L., ... & Allan, E. (2019). Direct and indirect effects of invasive species: Biodiversity loss is a major mechanism by which an invasive tree affects ecosystem functioning. Journal of Ecology, 107(6), 2660-2672.
[44] Masakha, E. J. (2013). Environment Impact Assessment of Invasive Prosopis Juliflora Weed in Salabani Location, Marigat District, Baringo County (Doctoral dissertation, Egerton University).
[45] Maundu, P., Kibet, S., Morimoto, Y., Imbumi, M., & Adeka, R. (2009). Impact of Prosopis juliflora on Kenya's semi-arid and arid ecosystems and local livelihoods. Biodiversity, 10(2-3), 33-50.
[46] Mbaabu, P. R., Ng, W. T., Schaffner, U., Gichaba, M., Olago, D., Choge, S., ... & Eckert, S. (2019). Spatial evolution of Prosopis invasion and its effects on LULC and livelihoods in Baringo, Kenya. Remote sensing, 11(10), 1217.
[47] Muller, G. C., Junnila, A., Traore, M. M., Traore, S. F., Doumbia, S., Sissoko, F., ... & Beier, J. C. (2017). The invasive shrub Prosopis juliflora enhances the malaria parasite transmission capacity of Anopheles mosquitoes: a habitat manipulation experiment. Malaria journal, 16, 1-9.
[48] Mumina, J., & Bourne, M. (2020). Policy Review and Analysis for the Formulation of the Kenya Agroforestry Strategy (2020-2030). World Agroforestry (ICRAF).
[49] Mwangi, E., & Swallow, B. (2005). Invasion of Prosopis juliflora and local livelihoods: Case study from the lake Baringo area of Kenya. Nairobi, Kenya: World Agroforestry Centre, 22, 1-68.
[50] Mwania, D. K. (2017). Distribution and Density of the Invasive Plant Species, Prosopis juliflora, in the Western Turkana Region of Northern Kenya (Doctoral dissertation, Ohio University).
[51] Mworia, J. K., Kinyamario, J. I., Omari, J. K., & Wambua, J. K. (2011). Patterns of seed dispersal and establishment of the invader Prosopis juliflora in the upper floodplain of Tana River, Kenya. African Journal of Range & Forage Science, 28(1), 35-41.
[52] Nabhan, G. P. (2018). Mesquite: An Arboreal Love Affair. Chelsea Green Publishing.
[53] Nadio, E. C., Agevi, H., & Obiri, J. (2020). Impacts of Prosopis juliflora on Abundance and Species Diversity of Forage Species in Turkana County, Kenya.
[54] Narain, P. (2008). Dryland management in arid ecosystem. Journal of the Indian Society of Soil Science, 56(4), 337-347.
[55] Nath, K., Panchani, S. C., Patel, T. M., Dave, H. K., Patel, V. B., Tiwari, K. K., & Sahoo, N. (2020). Evaluation of Prosopis juliflora as a potential feedstock for the production of sodium lignosulfonate from the spent liquor of a laboratory digester. Journal of Wood Chemistry and Technology, 40(5), 331-347.
[56] Ng, W. T., Cândido de Oliveira Silva, A., Rima, P., Atzberger, C., & Immitzer, M. (2018). Ensemble approach for potential habitat mapping of invasive Prosopis spp. in Turkana, Kenya. Ecology and Evolution, 8(23), 11921-11931.
[57] Northern Territory Government - Department of Land Resource Management. (2015). Weed Management Plan for Mesquite (Prosopis spp.).
[58] Odhiambo, M. R. (2016). Il Chamus verses the State: Vulnerability, Litigation and Resilience Building in the Baringo Lowlands of Kenya (Doctoral dissertation, Universität zu Köln).
[59] Oduor, N., & Githiomi, J. K. (2013). Fuel-wood energy properties of Prosopis juliflora and Prosopis pallida grown in Baringo District, Kenya.
[60] Okumu, J. A. (2019). Determination of factors influencing adoption and control of prosopis juliflora in Marigat, Baringo County, Kenya (Doctoral dissertation, Egerton University).
[61] Opiyo, F. E. (2014). Climate variability and change on vulnerability and adaptation among Turkana pastoralists in north-western Kenya (Doctoral dissertation, University of Nairobi).
[62] Palmer, W. A., Heard, T. A., & Sheppard, A. W. (2010). A review of Australian classical biological control of weeds programs and research activities over the past 12 years. Biological Control, 52(3), 271-287.
[63] Pasiecznik, N. M., Felker, P., Harris, P. J., Harsh, L., Cruz, G., Tewari, J. C., ... & Maldonado, L. J. (2001). The Prosopis juliflora-Prosopis pallida complex: a monograph (Vol. 172). Coventry, UK: HDRA.
[64] Pasiecznik, N. M., Harris, P. J., & Smith, S. J. (2004). Identifying tropical Prosopis species: a field guide (p. 29). Coventry, UK: Hdra Publishing.
[65] Patnaik, P., Abbasi, T., & Abbasi, S. A. (2017). Prosopis (Prosopis juliflora): blessing and bane. Tropical Ecology, 58(3), 455-483.
[66] Prabha, D. S., Dahms, H. U., & Malliga, P. (2014). Pharmacological potentials of phenolic compounds from Prosopis spp.-a. J. Coast. Life Med, 2, 918-924.
[67] Rasanen, L. A., & Lindstrom, K. (2003). Effects of biotic and abiotic constraints on the symbiosis between rhizobia and the tropical leguminous trees Acacia and Prosopis.

[68] Sakthieswaran, N., & Sophia, M. (2020). Prosopis juliflora fibre reinforced green building plaster materials—An eco-friendly weed control technique by effective utilization. Environmental Technology & Innovation, 20, 101158.
[69] Shackleton, R. T., Le Maitre, D. C., Pasiecznik, N. M., & Richardson, D. M. (2014). Prosopis: A global assessment of the biogeography, benefits, impacts and management of one of the world's worst woody invasive plant taxa. AoB PLANTS, 6.
[70] Shaheen, S., Fateh, R., Younis, S., Harun, N., Jaffer, M., Hussain, K., ... & Khan, F. (2020). Light and scanning electron microscopic characterization of thirty endemic Fabaceae species of district Lahore, Pakistan. Microscopy research and technique, 83(12), 1507-1529.
[71] Shanwad, U. K., Chittapur, B. M., Honnalli, S. N., Shankergoud, I., & Gebremedhin, T. (2015). Management of Prosopis juliflora through chemicals: A case study in India. Management, 5(23).
[72] Sharifi-Rad, J., Kobarfard, F., Ata, A., Ayatollahi, S. A., Khosravi-Dehaghi, N., Jugran, A. K., ... & Martins, N. (2019). Prosopis plant chemical composition and pharmacological attributes: Targeting clinical studies from preclinical evidence. Biomolecules, 9(12), 777.
[73] Sharma, P. C., & Singh, A. (2019). Reviving the productivity of salt-affected lands: technological options, constraints and research needs. Research Developments in Saline Agriculture, 591-627.
[74] Shibru, W. (2015). Socio-Economic and Ecological Impact of Prosopis Juliflora in Lower Awash, Afar National Regional State, Ethiopia (Doctoral Dissertation, St. Mary's University).
[75] Shiferaw, H., Teketay, D., Nemomissa, S., & Assefa, F. (2004). Some biological characteristics that foster the invasion of Prosopis juliflora (Sw.) DC. at Middle Awash Rift Valley Area, north-eastern Ethiopia. Journal of arid environments, 58(2), 135-154.
[76] Singh, G. (2022). Role of Prosopis in reclamation of salt-affected soils and soil fertility improvement. In Prosopis as a Heat Tolerant Nitrogen Fixing Desert Food Legume (pp. 27-54). Academic Press.
[77] Singh, N., & Pareek, A. (2023). Prosopis cineraria: a potential functional food for improving sports performance. Vegetos, 1-5.
[78] Slate, M. L., Tsombou, F. M., Callaway, R. M., Inderjit, & El-Keblawy, A. A. (2020). Exotic Prosopis juliflora suppresses understory diversity and promotes agricultural weeds more than a native congener. Plant Ecology, 221, 659-669.
[79] Throop, H. L., & Archer, S. R. (2008). Shrub (Prosopis velutina) encroachment in a semidesert grassland: spatial–temporal changes in soil organic carbon and nitrogen pools. Global Change Biology, 14(10), 2420-2431.
[80] Tilahun, M., Birner, R., & Ilukor, J. (2017). Household-level preferences for mitigation of Prosopis juliflora invasion in the Afar region of Ethiopia: a contingent valuation. Journal of environmental planning and management, 60(2), 282-308.
[81] Tu, M., Hurd, C., & Randall, J. M. (2001). Weed control methods handbook: tools & techniques for use in natural areas.
[82] van Klinken, R. D., Fichera, G., & Cordo, H. (2003). Targeting biological control across diverse landscapes: the release, establishment, and early success of two insects on mesquite (Prosopis spp.) insects in Australian rangelands. Biological Control, 26(1), 8-20.
[83] Vitelli, J. S., & Pitt, J. L. (2006). Assessment of current weed control methods relevant to the management of the biodiversity of Australian rangelands. The Rangeland Journal, 28(1), 37-46.
[84] Wakie, T. T., Laituri, M., & Evangelista, P. H. (2016). Assessing the distribution and impacts of Prosopis juliflora through participatory approaches. Applied geography, 66, 132-143.
[85] Wakie, T., Evangelista, P., & Laituri, M. (2012). Utilization assessment of Prosopis juliflora in Afar region, Ethiopia. US Forest Service, USDA Office of International Programs, USAID Pastoral Livelihoods Initiative II Project (PLI II), 1-15.
[86] Witt, A., & Luke, Q. (2017). Guide to the naturalized and invasive plants of eastern Africa. CABI.
[87] Wudad, A., & Abdulahi, A. (2021). Expansion of Prosopis juliflora and land use land cover change in korahey zone of Somali regional state, eastern Ethiopia. Journal of Materials and Environmental Science, 12(5), 728-737.
[88] Zachariades, C., Hoffmann, J. H., & Roberts, A. P. (2011). Biological control of mesquite (Prosopis species)(Fabaceae) in South Africa. African Entomology, 19(1), 402-415. Zeila, A. (2011). Mapping and managing the spread of Prosopis Juliflora in Garissa County, Kenya (Doctoral dissertation, Kenyatta University).
[89] Zimmermann, H. G. (1991). Biological control of mesquite, Prosopis spp.(Fabaceae), in South Africa. Agriculture, ecosystems & environment, 37(1-3), 175-186.