The invasive species *Prosopis juliflora* and its spread in coastal Kenya

1. Introduction

Biological invasions have become a major threat to global biodiversity.
Defined as the spread of invasive species, or alien species, biological invasion is one of the main causes of species extinction.
One example of such a biological invasion is that of *Prosopis juliflora (Sw.) DC*, which is considered a top global invasive species (de Souza Nascimento et al., 2014).
While there are many different definitions of an invasive species, the most common one refers to an introduced species - indigenous to a different region - which grows quickly and vigorously, spreads over a wide geographic area and has a negative impact on biodiversity (Ehrenfeld, 2010).

In response to the growing threat posed by invasive species, the Convention on Biological Diversity (CBD) was formed. The CBD, an international environmental agreement signed by 168 countries, calls upon parties to 'prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species' (Article 8h).
Since *Prosopis juliflora* is said to have a potential of invading nearly half of Kenya's land area, rapid intervention is urgently required (Shackleton et al., 2014).

The first documented case of *Prosopis juliflora* in Kenya occurred in 1973 in Bamburi (Mombasa County), near the city of Mombasa. In the years that followed, more individual plants were introduced until cultivation on a large and extensive scale began in 1983 in Baringo county and the Bura region (Taita-Taveta County). The large-scale cultivation of *Prosopis juliflora* was promoted by government agencies and NGOs, who recommended the plant due to its suitability for dry areas.
It was not until 2008, when the Kenyan minister for agriculture declared *Prosopis juliflora* a noxious weed (Maundu et al., 2009).

2. Description

Prosopis juliflora is native to rangelands in Mexico and Central and Northern South America, where it grows as a shrub or small tree. *Prosopis juliflora* is colloquially known in Kenya by its Swahili name, *Mathenge*, or, more popularly, as *Mesquite*, which is a general term used for many of the 44 species belonging to the genus *Prosopis*. All are part of the family Fabaceae, also called Leguminosae (BioNET-EAFRINET, o. J.).

Prosopis juliflora can grow as a shrub or tree with a height of up to 15 m. It often has multiple stems, which tend to grow in a jagged fashion. On each turn of the zig-zag shaped branches, there are one or two thick thorns that can reach up to 5 cm length. The bark is grey-green in colour and becomes rougher and scalier with time.
Bipinnate leaves, typical for Prosopis and other species of Fabaceae, are 6-8 cm long and made of 12-25 pairs of smaller pinnae. These narrow and tiny leaves usually range from 6-16 mm long and 1.5-3.2 mm wide.
The flowers of *Prosopis juliflora* are 5-10 cm long and look similar to a brush, composed of dense yellow spikes. They turn into green

pods - of about 10-20 cm long, often slightly curved – and become yellow when they ripen (BioNET-EAFRINET, o. J.).
Inside each pod is approximately 10-20 small oval seeds, that are dispersed by browsers such as goats, camels and some wild animals who feed on them. Seeds can also be distributed by floodwaters and surface runoff (Nawata, 2012). Overall, one tree can produce between 630,000 and 980,000 seeds per year (de Souza Nascimento et al., 2014).The roots of *Prosopis juliflora* reach deep into the ground to moist layers of soil and sub-surface water (El-Keblawy & Al-Rawai, 2005).

a. Thorns of Prosopis juliflora

b. Flowers of Prosopis juliflora

Due to its origin, *Prosopis juliflora* is adapted to arid and semi-arid climates and so is capable of surviving and growing in a harsh desert environment. For example, the depth of the roots is an adaption to water scarcity. Seeds germinate in both full light and complete darkness and in a wide range of air temperatures up to 50 °C and soil temperatures up to 70 °C (Damasceno et al., 2018). Although high soil salinity does have a negative impact on seed germination (El-Keblawy & Al-Rawai, 2005), *Prosopis juliflora* is generally capable of thriving in sandy, rocky, poor and saline soils and reaches altitudes between 300-1900 m above sea level (BioNET-EAFRINET, o. J.). Its rapid growth and large quantity of seeds also contribute to *Prosopis juliflora's* survival and spread (Damasceno et al., 2018).

In addition to characteristics that help survive *Prosopis juliflora* in very inhospitable regions, the species also benefits from defence mechanisms like thorns against herbivores and neighbouring plants.
An additional adaptation that allows *Prosopis juliflora* to quickly invade and dominate an ecosystem is the ability to release allelochemicals from its roots, leaves and fruits. Allelochemicals are substances produced by organisms to react to abiotic and biotic factors in their environment.
This in turn allows *Prosopis juliflora* to inhibit seed germination or growth of surrounding plants, while it is unaffected by other plants allelochemicals (Damasceno et al., 2018).

3. Use and problems

Use

The introduction of *Prosopis juliflora* to Kenya, as well as other countries in South and East Africa, many coastal regions of Asia and to America and Australia, occurred primarily in rural areas (de Souza Nascimento et al., 2014). People where told about the various advantages and economic benefits of *Prosopis juliflora*, such as using the plant for firewood or charcoal production, shade and fodder for livestock.

Interviews with people of the Afar region in Ethiopia on *Prosopis juliflora* revealed that the plant was frequently associated with animals and cattle (Wakie, Laituri, et al., 2016).

Moreover, *Prosopis juliflora* was introduced to prevent further soil degradation from advancing desertification that occurs in many arid and semi-arid regions due to activities like overgrazing and deforestation. As stated above, *Prosopis juliflora* is capable of surviving in harsh environments and has the potential to stabilize sandy ground sensitive to erosion (Nawata, 2012). Additionally, as with many other leguminous plants, it is capable of creating a symbiosis with Rhizobia, a group of bacteria that allows these plants to fix atmospheric nitrogen, which ultimately fertilizes the soil (de Souza Nascimento et al., 2014).
Due to these perceived benefits, the Ethiopian government even initiated a programme planting *Prosopis juliflora* in the 1970's to “green” the region of Gewane and Amibarato, limit further desertification and prevent drought (Wakie, Laituri, et al., 2016).

Studies have also investigated the antifungal and antibacterial activity and potential use of the plant (Damasceno et al., 2017). Furthermore, *Prosopis juliflora's* wood is used as timber for the construction of furniture or fences (Wakie, Laituri, et al., 2016), and for various medicinal purposes. For example, a South African company has developed a medicine derived from *Prosopis juliflora's* pods to lower people's blood sugar. Other uses of *Prosopis juliflora* are in the cosmetic industry, biotechnology and even in the food industry, since it is possible to produce food items like flour from *Prosopis juliflora* (Damasceno et al., 2018).

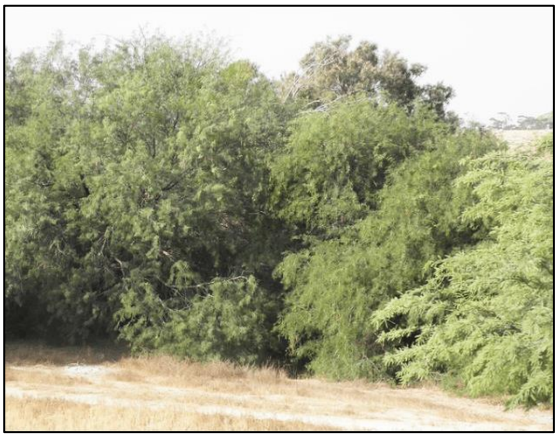
Problems

By 2014, the *Prosopis juliflora* was found in 129 countries (Shackleton et al., 2014), where it was fought as an invasive species. Such plants are defined as introduced species, capable of growing fast and spreading widely, hence having a negative impact on biodiversity and ecosystems (Ehrenfeld, 2010). Todayc, *Prosopis juliflora* is considered internationally to be among the most problematic invasive species (de Souza Nascimento et al., 2014).

While initially introduced as a desired plant, governments, NGOs and scientists realized the risks and dangers posed by *Prosopis juliflora*, it caused a change of perspective. For example, after its introduction at the beginning of the 20th century, the Sudanese government stopped planting *Prosopis juliflora* in the 1990s and started programs to eliminate it (Nawata, 2012). There are now numerous studies as well as publications by government administrations describing the dangers posed by *Prosopis juliflora* and presenting various approaches to address its spread.

In comparison to many native species, *Prosopis juliflora* has a higher competitive advantage. While indigenous plants of rangelands may also be adapted to their environment, they lack the necessary defence mechanisms to compete with or restrict *Prosopis juliflora.* This issue also applies also to agricultural plants (de Souza Nascimento et al., 2014).

The allelochemicals released by *Prosopis juliflora* inhibit the growth and seed germination of nearby plans, whereas *Prosopis juliflora* itself is immune to the allelochemicals of other plants (Damasceno et al., 2018). Additionally, *Prosopis juliflora* grows much faster than many other plants and so reduces the available space by rapidly forming dense thickets. These adaptations make it nearly impossible for nearby native plants to grow (Wakie, Laituri, et al., 2016). Hence, indigenous species are being pushed back by the spread of *Prosopis juliflora,* resulting in changes to regional ecosystems and causing shifts in spatial patterns (Nawata, 2012). A decrease of individuals of indigenous species may also lead to a complete extinction. When the direct cause of extinction is identifiable, introduced species are the most common one (McNeely, 2001).



c. Thickets of Prosopis juliflora

Due to the complex structure of ecosystems, a change in the flora also causes a change in the fauna. Herbivore insects have adapted to indigenous plants during evolution. With their decrease the quality and quantity of food for insects may drop, both species-related and individual-related (Proche et al., 2008). Particularly at risk are those species, that rely on just a few plants to feed on (oligophagous), or even just one species (monophagous).
The impact on insects can then further influence their predators, like, for example, birds. This ripple effect can continue until the whole ecosystem has changed. These consequences are difficult to understand and predict.

Other ways that *Prosopis juliflora* affects local fauna is through its allelochemicals. Although *Prosopis juliflora* is used for animal feed, it can be harmful to them due to poisonous substances in the pods. Toxicity occurs when the pods are eaten almost exclusively and over a long period of time, which often occurs during droughts as the pods form an important part of the animal's fodder during this time. Ultimately, animals suffer from muscle dysfunctions, weight loss and even death (Damasceno et al., 2017; Nawata, 2012). People also observed other phenomena like diarrhoea, the loss of goats' teeth or fruit gum that sticks to them, fibrous remains blocking animals rumens (Chepkwony, 2018; Maundu et al., 2009) and also physical injuries from the thorns (Wakie, Laituri, et al., 2016).

While all types of animals are affected, cattle and camels are on top of the list, followed by sheep and goats. The death of livestock often comes along with a degradation of people's livelihood (Wakie, Laituri, et al., 2016).

Yet, people are also affected directly by *Prosopis juliflora*, not only through their animals. The rapid growth of enormous thickets depletes water resources and prevents both people and animals from reaching water wells or other infrastructures (Shackleton et al., 2014; Wakie, Laituri, et al., 2016).
Furthermore, thickets can be a hiding place for criminals and dangerous animals (Maundu et al., 2009; Wakie, Laituri, et al., 2016).

Moreover, the purported economic benefit of *Prosopis juliflora* through charcoal sales is no longer applicable, as the Kenyan government instituted a moratorium on unlicensed logging and charcoal production.

In terms of soils, *Prosopis juliflora* can stabilize sand dunes and so prevent erosion. Nevertheless, this isn't applicable to all areas, as in other cases it enhances the loss of fertile soil and growth of massive sand dunes (Nawata, 2012; Shackleton et al., 2014).

Wakie et al. (2016) notes that the native plants displaced by the invasive species are often the ones indigenous people rely on for different uses like construction materials and furniture, tools, firewood, food, medicinal purposes and most importantly animal food (Wakie, Laituri, et al., 2016). Particularly affected are fodder plants like different grass species and *Acacia* trees (Maundu et al., 2009; Wakie, Laituri, et al., 2016).
The displacement of native plant species also results in a dependence on *Prosopis juliflora,* because it is widely available in their environment and there is a lack of alternatives to meet livelihood demands (Maundu et al., 2009).
Further, one of the biggest dangers of *Prosopis juliflora* is the physical danger they pose. Not only do the thorns puncture and damage shoes, tires and so on, they also hurt people. Maundu et al. (2009) investigated the spread and impact of *Prosopis juliflora* in Kenya and interviewed people from different regions. On top of the list of threats people named where physical injuries, that sometimes resulted not only in pain but also in infection or even death.

Prosopis juliflora is also connected to Malaria. A study in Mali investigated the connection between the invasive species and various parameters of *Anopheles* mosquitos, which transmit the parasites Plasmodium responsible for Malaria. The results confirmed that the existence of *Prosopis juliflora* enhanced the mosquito's transmission capacity of Plasmodium (Muller et al., 2017).

This finding further demonstrates the need to take action and to join other countries already taking measures. Finding a solution is also particularly important for the vulnerable environment of coastal Kenya.

4. Spread in Kenya

Today, *Prosopis juliflora* is invasive in many countries away from its original distribution areas in Mexico and North and Central South America. In 2009 it had already spread throughout the arid and semi-arid regions of North, West, East and Southern Africa, the West of the Arabian peninsula, South East Asia, South West Australia, Southern USA and the South of Brazil and Uruguay (Maundu et al., 2009). In 2014, *Prosopis juliflora* was documented in 129 countries (Shackleton et al., 2014).

In Kenya, the rapid spread began in the regions of the first large-scale plantations – Baringo County and Bura (Taita-Taveta County), but also in Turkana County, where the densest thickets can be found today.

Generally, arid and semi-arid areas have the largest infestations. In Kenya, this includes the East and North East the country as well as regions in the Rift Valley and on the coast. In drier areas, *Prosopis juliflora* benefits from lakes (Lake Baringo), river systems (Tana and Turkwel) and seasonally flooded areas like the Lotikipi plains and disturbed areas such as farms and urban areas (Maundu et al., 2009).

The rivers Turkwel and Tana - including Tana River Primate National Reserve and Arawale National Reserve - and the Lotikipi Plains are particularly sensitive ecosystems, that are now threatened by *Prosopis juliflora*. The plains form an important grazing area for the local Turkana people. Other conservation areas affected include the Lake Bogoria National Reserve, Shaba National Reserve, Samburu National Reserve and Marsabit National Reserve as well as Mount Kulal Biosphere Reserve and the Tsavo National Parks (Maundu et al., 2009).

The appearance of *Prosopis juliflora* in the area of Watamu (Kilifi county) threatens local ecosystems. This particularly applies to the Kenyan coastal forest. More than 80 % of the area is under some kind of protection (Matiku et al., unk.), and more than half of Kenya's rare plants are found in the coast region (WWF Kenya, unk.). Not only is the forest of social and economic importance for the region, but it is also internationally recognized for its unique and biologically rich ecosystems and landscapes. Ecosystems on the coast vary between rangelands, woodlands, terrestrial forests, mangroves, mudflats, coral reefs, seagrass beds, estuaries, beaches, sand dunes, rivers, lakes, wetlands, cultural and natural heritage sites. They provide natural resources for local communities, which are vital for supporting food security and subsistence activities in economic sectors like agriculture, fisheries, livestock, forestry, tourism, shipping, mining and energy. This significantly contributes to production and socio-economic development at the local and national level as well as safety and well-being of coastal communities (WWF Kenya, unk.).

An infestation of the coastal environment by *Prosopis juliflora* is likely to deteriorate the ecosystems' condition and compromise all benefits, and therefore must be prevented.

5. Possible solutions

Over time, it seems that the costs of *Prosopis juliflora* – including the loss of livestock, expensive management and so on - exceed its benefits. When the invasion progresses, the intraspecific competition increases and the plants produce less pods, which are the main beneficial resource of *Prosopis juliflora.* Instead, it forms dense thickets that make its use more difficult and cause negative impacts like the loss of grazing land, blocked infrastructures among others. Hence, many countries have implemented some form of management to address the issue (Shackleton et al., 2014).

Using models, Shackleton et al. (2014) assessed the management plans of countries and found, that there is a link between action and knowledge about the species. It was shown that the more information countries had about *Prosopis juliflora*, the better their management was. From this, it is clear that increased knowledge on the plant and effective communication to the public is essential to effective management.

There are various options of managing invasive species, even leading to conflicts of interest regarding which one to use to preserve, exploit or enhance the plant's benefits while reducing negative impacts. In the end, the country's socioeconomic status and the extent of the species' spread play a key role in determining which management is used (Shackleton et al., 2014).
Management options include

(1) mechanical and chemical control,
(2) biological control
(3) control through utilization
(4) other control and
(5) integrated management,

which come along with different advantages and disadvantages.

Mechanical and chemical control

This form of management is mostly used in wealthier countries and those with a minimal spread of *Prosopis juliflora.* Mechanical control can be financially costly, which became apparent in South Africa where a partial removal of *Prosopis juliflora* costed 2828 US Dollar per hectare (Shackleton et al., 2014)
Therefore, it is important to use limited financial (but also human) resources in the most effective way.

In mechanical control, the plant can be killed by removing all of its roots to a depth of 30 cm, preventing it from sprouting again. This can be achieved with different techniques from stick raking and grubbing to blade ploughing and chain pulling, the latter being the cheapest but also the least effective method. Chain pulling is recommended in combination with fire or chemical treatment (Northern Territory Government, 2015). In terms of costs and benefits blade ploughing is the best option, which - according to the Australian Weed Management Guide on Mesquite (2003) - costs about 120 Australian Dollar per hectare in dense infestations. In such areas, a bulldozer can also be used as a last resort (Northern Territory Government, 2015).
Mechanical control prepares the soil for grass pastures, which can be assisted by sowing grass seed. Since this also applies to the seeds of *Prosopis juliflora* – which regenerates vigorously and has durable seeds - a follow up control and monitoring is essential.
(CRC for Australian Weed Management et al., 2003).

Australia also applies chemicals to combat different *Prosopis* species. One technique is the basal bark treatment, where an herbicide is sprayed around the entire stem up to 7,5 cm from the ground. Another method is the cut-stump technique. After cutting the tree horizontally, only leaving a stump very close to the ground, the herbicide is applied within 15 seconds.
For seedlings, it is recommended to spray foliar herbicide over the entire plant. These plants should not be higher than 1,5 m and should have large area of foliage (CRC for Australian Weed Management et al., 2003; Northern Territory Government, 2015).

Both mechanical and chemical control are suitable to remove *Prosopis juliflora* at a large scale, but are also the most expensive controlling methods (Shackleton et al., 2014).
Regarding chemical control with herbicides, their potentially harmful effects on human and environmental health risks must not be neglected.

Biological control

Introducing a natural enemy of the invasive species is a common way to deal with biological invasions. Both in Australia and South Africa, these so-called biological control agents were released, although not very successful in the latter.
In Australia, however, two were able to establish widely (Shackleton et al., 2014). Species of the genus *Evippe*, a leaf-tying moth from Argentina, have been able to severely affect *Prosopis* populations. The introduction of the beetle *Algarobius prosopis,* which feeds on seeds, was also very successful, whereas it failed to establish in South Africa (Shackleton et al., 2014; Zachariades et al., 2011). Seed-feeding insects can regulate expansion of the plant but will not contribute to its removal. Instead, by thinning them, the insects prevent the formation of thickets, increasing future usefulness. (Zachariades et al., 2011).
To reach damaging densities the climate of the area affected should meet the control agent's demands. Also, possible predators of the species must be considered, as well as other requirements. Hence, comprehensive preparation is needed, which is often best determined through a model. This analysis helps estimating whether and where the species can be released and how it would spread (van Klinken et al., 2003). The success of *Algarobius prosopis* in Australia and the failure of the same species in South Africa reflect the importance of individually assessing which species is suitable for which region.

Furthermore, a permit for the release of a biological control agent is required. Precautionary measures are necessary due to possible negative side effects on the environment, such as attacks on non-target species. One of the most popular examples is the introduction of the cane toad in Australia, which was supposed to help with pest control but became a nuisance instead.

In this case, there is concern that control agents might attack indigenous species of *Prosopis* such as *Prosopis africana*. On the other hand, *Algarobius prosopis* is already spread in the range of the plant but has not been recorded from it (Zachariades et al., 2011).

Before releasing species like the very successful ones of *Evippe*, model analysis can be made by institutions such as the IPM Innovation Lab, which already helped to secure a permit to release the leaf-feeding beetle *Zygogramma bicolorata* in Kenya and Uganda (Hendery, 2019).

d. A beetle of the genus *Algarobius*

An advantage of biological control is the low costs, especially when compared to mechanical and chemical control. After the control agents are released, minimal associated costs are necessary as monitoring is required. Another advantage over mechanical control is the possible application of a control agent in large or inaccessible areas.

While implementation costs are relatively low, initial research, on the other hand, is expensive. In addition, in some areas control agents have not yet had a substantial impact on density and spread. People that rely on *Prosopis juliflora* for their livelihood are nevertheless concerned (Shackleton et al., 2014).

Control through utilization

A common argument against the control of invasive *Prosopis juliflora* is its usefulness.

Hence, combining management with utilization can be a reasonable compromise.

This method is especially useful in poorer parts of the world, where expensive management such as mechanical control is not feasible.

In Kenya, the government, the FAO and several NGOs have taken time and effort to initiate programmes and build capacities to inform people about how to benefit from *Prosopis juliflora* (Shackleton et al., 2014). In addition to many small-scale projects, a cookbook was created to make use of the flour produced from the pods (Choge et al., 2007; Shackleton et al., 2014). Moreover, a thermal power station has recently been built in Baringo county where energy is produced by burning biomass of *Prosopis juliflora* (Herbling, 2016).

Since regular pruning for charcoal production has proven to be a profitable way to take advantage of *Prosopis juliflora* while controlling it at the same time (Wakie, Hoag, et al., 2016), some argue that it should be allowed for this species - bearing in mind the areas potential as another seed source.

Using *Prosopis juliflora* to generate income, for instance by producing charcoal, can also reduce overexploitation of indigenous species (Shackleton et al., 2014).

Control through utilization allows people to benefit from *Prosopis juliflora* and therefore promotes local development. In 2012, income from trading the products of *Prosopis* species was estimated more than 1,5 million US Dollar in four selected areas. Despite the initial costs, for instance to inform people about different options to use the plant, this form of management is considered to be cheaper than the alternatives (Shackleton et al., 2014). Instead of investing money, the control itself becomes profitable.

Despite some advantages, controlling *Prosopis juliflora* through utilization also has negative impacts.
First, the effectiveness depends on the desired result, namely whether *Prosopis juliflora* should be completely eliminated or just prevented from spreading further. While many locals support the use and therefore the existence of *Prosopis* species, many others consider complete eradication as the best solution (Shackleton et al., 2014).
There also remains doubt about how much the utilization of *Prosopis juliflora* actually contributes to its control, although it is evident that practices like flour production destroy large amounts of seeds - approximately two million per tonne (Shackleton et al., 2014). However, utilization could also lead to further distribution of seeds and thus increase the spread (Wakie, Hoag, et al., 2016).

Promoting the use of *Prosopis juliflora* can be challenging, since it is often considered inferior to native plants.
It also has the potential to push people into a business that creates a dependency, resulting in opposing attitudes towards *Prosopis juliflora* and conflicts of interest between stakeholders and the rest of the population. Furthermore, plants differ from region to region, leaving some people with less valuable types that may have more thorns, bitter pods and so on.
Ultimately, the locational conditions determine on the actual potential for utilization (Shackleton et al., 2014).

To avoid these problems and dangers of the utilization of *Prosopis juliflora*, indigenous plants with comparable or better attributes for specific uses can be promoted and planted. For example, *Acacia tortilis* is preferred by cattle to feed on the pods, plenty of other trees are also suitable for providing shade (*Salvadora persica, Boscia angustifolia and Boscia coriacea*) and *Terminalia spinosa*, for example, can be used for poles (Maundu et al., 2009).

Other control, integrated management and overall management needs

Other control

Other forms of control can also be used. One example is using fire to burn the plants, which is considered an inexpensive management method.
While fire might not harm *Prosopis juliflora*, since it is only known to cause severe damage to *Prosopis pallida*, it can reduce its spread by removing vegetation and killing seeds on the ground.
Very intense fires could also kill other Prosopis species like *Prosopis juliflora* but do require more preparation. Enough fuel must be provided, which can be achieved by using mechanical control such as chaining or reducing grazing before burning, and safety measures must be taken so that non-targets stay untouched. The latter are also a reason that fire cannot be used in all areas due to increased risk of wildfires.
Ultimately, a permit should also be acquired before this approach is attempted (CRC for

Australian Weed Management et al., 2003; Shackleton et al., 2014).

Another method is the so-called (partially) girdling. A strip of the stem is removed before the growing season of the plant starts. It should be at least 10 cm wide, reach deeply into the hard wood and go almost completely around the tree. What remains is a vertical part of the stem (1/10 of the girth) that still allows the transport of nutrient reserves from the roots to the crown. The weakening of the tree leads to high nutrient consumption, and when the remaining strip of the stem is removed - as well as the callus tissue and all shoots from the stem - the assimilate transport is interrupted and photosynthesis products cannot revert back to the root. The last strip is usually removed after the growing season. It is recommended to repeat the procedure the next growing season(s), to kill the plant completely (Böcker & Dirk, unk.).
Girdling has been applied in Europe to control the invasive *Robinia pseudoacacia*, which also belongs to the family of Fabaceae/Leguminosae.
The method inhibits massive sprouting after cutting back the tree, a common nature of both *Prosopis juliflora* and *Robinia pseudoacacia.*
It is also a relatively inexpensive, efficient and sustainable technique, in which the tree dies automatically after some time (Böcker & Dirk, unk.).

Nevertheless, girdling has never been implemented with *Prosopis juliflora.* The species might react differently, also because the environment is a different one. The best results are achieved when the interventions are adapted to the beginning and the end of the growing season.
Additionally, the method is difficult to implement with small trees, multiple stems or thickets, because it takes some effort to apply to every tree (Böcker & Dirk, unk.).

Integrated management

In 2014, almost half of the countries affected had an integrated management approach. This includes three or more methods of those described above – biological control, mechanical control, chemical control, control through utilization and other control (Shackleton et al., 2014). This type of management is often chosen by countries that have acquired a lot of knowledge about *Prosopis juliflora*, and it combines the advantages (and disadvantages) of the various individual methods. In South Africa, mechanical, chemical and biological control is used (Shackleton et al., 2014). Integrated management generally results in a better cost—benefit ratio and higher effectiveness in a long run (Northern Territory Government, 2015).

Overall management needs

Every form of management can be supported by certain framework conditions. As mentioned before, knowledge determines whether and which management is applied and is vital to address invasive species effectively (Shackleton et al., 2014). This is achieved, for example, with information about the plant’s characteristics, where and how densely it has spread or could potentially spread in the future (Clout & Williams, 2009).
Knowledge is also essential to maximize the cost-benefit ratio and invest resources optimally.
For example, it is possible to concentrate on areas where a further spread is most likely, or to take advantage of natural barriers preventing more spreading (Clout & Williams, 2009). Areas with a high risk of further spreading are, for example, water points where plants grow well and animals come to drink (Northern Territory Government, 2015).
Generally, it is better to intervene as early as possible.

In an early stage, the infested area and its boundaries are less extensive, the success rate is higher and the costs are lower (Clout & Williams, 2009). The management should be aligned with the growth and reproductive cycles of the species. Hence, control measures should be implemented before seed formation (Northern Territory Government, 2015).
Before taking action, it is also helpful to prioritise an invasive species like *Prosopis juliflora*. Fighting on several fronts at the same time can be very ineffective and might bring no results at all (Clout & Williams, 2009).

If a plant has been successfully limited, management has not yet ended. Seeds or other sprouting parts can easily lead to recurring infestations. Hence, follow up controls are necessary. In fact, successful management may take time and repetition to see desired results (Northern Territory Government, 2015).
Monitoring also provides feedback which can be used to modify, or, in case of a failed control, abandon the method of management (Clout & Williams, 2009; CRC for Australian Weed Management et al., 2003)
The further spread of *Prosopis juliflora* should be prevented. Sources of new infestations can be areas with livestock or plantations. The Australian Weed Management Plan for Mesquite (2015) recommends to quarantine animals for at least eight days before transporting them into uninfested areas. Moreover, grazing should be discouraged after control in order to promote the growth of grass and reduce new germination of *Prosopis juliflora* (CRC for Australian Weed Management et al., 2003).

Australia is also a model for developing a national management strategy and has published several papers about control measures. Through these resources, all parties affected, for example farmers and landowners, are informed about appropriate procedures. These could include working from clean areas towards infested areas and make sure machines coming from infestations with *Prosopis juliflora* are clean. A national overview also helps to coordinate large-scale management, which is essential for the best possible result (Northern Territory Government, 2015; Shackleton et al., 2014). In Kenya, there was a first meeting for a national management strategy from 24th- 29th November 2019, where the Kenya Forest Service, Kenya Wildlife Service, Ministry of Agriculture and others gathered to discuss potential approaches (Eschen, 2020).

Conclusion

Prosopis juliflora grows on 6 continents and 129 countries but is only native to one continent. By now, its invasive properties have exceeded its benefits and are threatening ecosystems and human health across the world. As a result, many countries are implementing measures to control the plant's spread.

In Kenya, *Prosopis juliflora* has already caused severe damage and is now spreading further in the coastal region of Kilifi county. The sensitive and unique coastal ecosystems are threatened, necessitating urgent action.
The Convention on Biological Diversity (CBD) calls for a control or eradication of alien species which threaten ecosystems, habitats and indigenous species, and is supported by the declaration of the Kenyan government on *Prosopis juliflora*, calling it a 'noxious weed'. Many countries have already started and implemented forms of control and management, which could serve as models for Kenya's future approaches.

It is still relatively inexpensive and easy to control *Prosopis juliflora* and implement management methods as it has not yet formed large-scale thickets or spread extensively and the success rate is still relatively high. Informing and involving local communities is also an essential element for the successful control and a satisfactory solution for everyone.

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Pictures

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c. Thickets of Prosopis juliflora; J.M. Dufour-Dror https://www.researchgate.net/figure/Dense-thicket-of-Prosopis-juliflora-in-wadi-Ashan-in-the-Beer-Sheva-area-Israel-Photo_fig2_308071319

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