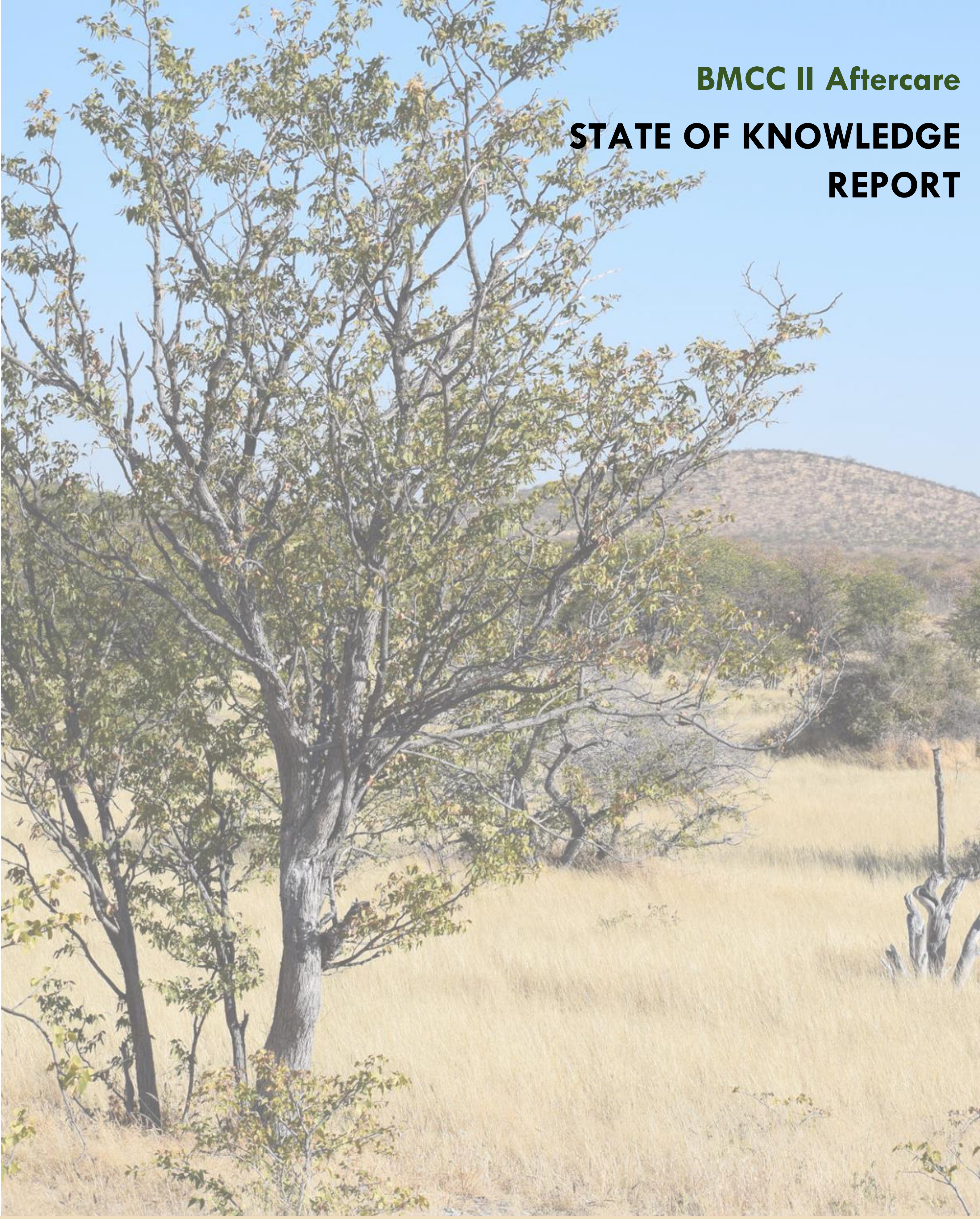
## BMCC II Aftercare

# STATE OF KNOWLEDGE REPORT

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# List of Acronyms

| | |
|---|---|
| AU | Agricultural Units |
| CO2 | Carbon dioxide |
| GHG | Greenhouse Gases |
| ha | Hectares |
| SAEIA | Southern African Institute for Environmental Assessment |
| UNCBD | United Nations Convention on Biological Diversity |
| UNCCD | United Nations Convention on Combatting Desertification |
| UNFCCC | United Nations Framework Convention on Climate Change |

# 1. Background

## 1.1. Woody Encroachment in Namibia and the World

The share of woody vegetation has increased throughout the entire world for the last 100 years. Across different bioclimatic zones, woody plants have displaced grasses and while trees dominate humid regions, unpalatable shrubs proliferate in arid regions. This is considered a type of degradation (Archer et al. 2017).

About 40% of Africa's surface area is covered by savanna ecosystems. The characteristic vegetation is large *Acacia* trees scattered in grasslands. The expansion of human activity and land uses has considerably changed many of these landscapes. Major environmental drivers including herbivory, fire, precipitation, nutrients and human activity have caused proportions of trees and grasses to shift (Tews et al. 2004).

Woody or bush encroachment is the increasing abundance of woody plants in savannas causing changes in grasslands, the natural vegetation composition and herbaceous cover (Lesoli et al. 2013). Bush encroachment has been a threat to Southern African rangelands for almost 100 years when the increase of *Acacia* was first described by Bews in 1917 (O'Connor et al. 2014). Encroaching woody species compromise ecosystem stability, impair productivity of rangelands and erode natural capital (Lesoli et al. 2013).

## 1.2. Extent of Bush Encroachment in Namibia

Bush encroachment has already been reported in Namibia by explorers in the 19$^{th}$ century with early explorers reporting dense patches of bush in some areas (Cunningham 2014). There are different estimates of the extent of bush encroachment in Namibia. Rothauge (2014) suggests that around 75% of Namibia's surface area are bush encroached, which would be around 62 million hectares at varying densities. He considered areas with bush density more than twice the annual rainfall as encroached (Rothauge 2014). The National GHG Inventory considers 58.2 million hectares as encroached, while a SAEIA study conducted in 2016 estimated 45 million hectares of bush encroached land (Seebauer et al. 2019). From the estimated 45 million hectares, about 23% (10.5 million hectares) occur in Otjozondjupa (Hengari 2018).

Due to the extent of bush encroachment in Namibia with densities of up to 6 000 bushes per hectare (in Otjozondjupa), it has become a separate indicator for land degradation in Namibia's Land Degradation Neutrality Target Setting. A key target is the reduction of bush encroachment on 18 880km$^2$ (1.9 million hectares) by 2040 (Hengari 2018). A study questioning more than 350 farmers all over Namibia indicated that bush encroachment has been increasing in severity over the years (Honsbein 2015).

Most encroaching species in the world belong to the genus *Acacia*, which includes more than 900 species and is the second largest genus. In areas with poor soil, the nitrogen fixing abilities of acacias can increase soil fertility, which allows them to gain a competitive advantage over other species (Lesoli et al. 2013). The main bush thickening species in Namibia are *Acacia nebrownii* (Soetdoring) and *Rhigozum trichotomum* (Driedoring) in the south, *Acacia mellifera* subsp. *definens* (Black thorn), *Acacia reficiens* (Red thorn), *Acacia erubescens* (Blue thorn), *Acacia luederitzii* (False umbrella thorn), *Dichrostachys cinerea* (Sickle bush), *Terminalia sericea* (Silver terminalia), *Colophospermum mopane* (Mopane) and *Terminaila prunioides* (Purple-pod terminalia) northern and eastern Namibia (Van Eck & Van Der Merwe 2004).

Woody plants in Southern African savannas are used as browse by wildlife and livestock, as construction material, firewood, for woodcarvings and the production of charcoal. Where trees are commercial exploited for timber, harvesting rates are often higher than replacement rates (Smit 2004).

## 1.3. Causes of Bush Encroachment

Key causes of bush encroachment in other countries of the world –such as changed fire regimes, grazing pressure caused by livestock and changes in climate- all apply to Southern Africa. However, additional drivers such as the strong decline of large browsers, past livestock pandemics (e.g. rinderpest), shifting human settlements, the extensive harvesting of woody biomass for fuel as well as land tenure and land-use patterns also influence the proliferation of bush in Southern Africa (O'Connor et al. 2014, Cunningham 2014). While soil types and rainfall are key determinants, herbivory and fire are secondary determinants (O'Connor et al. 2014). Both herbivory and fire can be managed (Smit 2004). These factors are essential for the functioning of African savannas (O'Connor et al. 2014).

Causes for woody encroachment are numerous and can include climate trends, land-use history and species adaptations in different bioclimatic zones. Different factors including fire, nitrogen deposition, atmospheric $CO_2$ concentrations, climate and grazing / browsing regimes interact with each other to constrain or promote the growth of woody encroachers. A change in just one of these factors may not be enough to trigger woody encroachment (Archer et al. 2017). Key drivers of woody encroachment can include:

## Grazers and Browsers

Throughout the world, grassland is primarily used for livestock grazing. The arrival of livestock coincided with increased woody abundance in many parts of the world. Livestock grazing influences the intensity and frequency of fire by removing fine fuels. In addition, livestock can effectively disperse seeds and displace browsers and other seed predators impairing natural controls and enhancing the recruitment of woody plants (Archer et al. 2017).

Grazing pressure by livestock can reduce fuel load and reduce the competition of grasses supporting the proliferation of bushes. Especially in conjunction with good rainfall, grazing pressure can support the development of woody seedlings (O'Connor et al. 2014). The artificial provision of water has supported continuous grazing. As a result, recovery phases for grasses were too short supporting species with earlier succession to dominate (Hoffmann et al. 2010). The restrictions caused by fences can limit both wildlife and livestock movement increasing grazing pressure in specific areas supporting the thickening of woody plants (Smit 2005).

Large browsers such as elephants, giraffes and rhinos can transform landscapes and considerably suppress woody encroachment. The populations of these large browsers have declined all over Southern Africa. Considerable evidence suggests that browsers alone can control bush encroachment (O'Connor et al. 2014).

## Climate

With a changing climate and changes in the frequency and duration of droughts, grasslands in many areas of the world could become desert shrubland. The carrying capacity for woody plants is determined by the mean annual precipitation (Sankaran et al. 2008; Bond 2008). Precipitation above a certain threshold may favour woodlands and forests (Archer et al. 2017). The recruitment of woody biomass is limited by water availability in areas that receive less than 650mm of rainfall per year. This creates a balance between grasses and trees. In wetter savanna ecosystems, external disturbances such as large herbivores and fire is required to maintain this balance (Tews et al 2004).

Woody plants and especially large trees require more rain than grasses to germinate and the rainfall frequency and intensity plays a large role (Smit 2004). The thickening of woody plants will thus depend on the seasonality of precipitation and rainfall infiltration. Rainfall during grass dormancy, frequent low intensity rainfall and large rainfall events can favour woody plants with their deep roots, while grasses prefer small rainfall events and summer rains that moisten uppers soil horizons (Archer et al. 2017). The root system of woody plants can extend to over seven times the extent of the canopy and consists of long tap roots and shallow roots that actively compete with grasses. The deep-reaching tap roots ensure that they can use deep water unavailable to grasses (Smit 2004; Ward et al. 2013).

Variability in rainfall influences plant growth, recruitment and mortality. The high variability in semi-arid zones can support the recruitment of woody plants (Archer et al. 2017).

## Topography and Soils

Grasses and woody plants use different soil resources. The roots of woody plants reach deeper, while the roots of grasses have a dense, fibrous system in limited depths exploiting the upper layers of the soil where nutrients and water concentrate. As a result, surface soils with a fine texture and shallow soils favour grasses. Deep and coarse soils with fast infiltration of water and nutrient leaching favour woody plants. Some woody species are generalists with deep tap roots and extensive lateral shallow root systems, which allows them to thrive in a range of growing season conditions (Archer et al. 2017).

In highly fertile patches, the establishment of bush may be constrained due to the increasing competitiveness of the grass layer and herbivores attracted to the patch (Porensky & Veblen 2011). Slopes can cause water and nutrients to accumulate downslope and can encourage higher densities of woody plants (Archer et al. 2017).

## Atmospheric $CO_2$

Atmospheric $CO_2$ has increased over time. This rise in atmospheric $CO_2$ can potentially favour $C_3$ plants over $C_4$ grasses. Most woody encroachers are $C_3$ plants, while most tropical grasslands are dominated by $C_4$ grasses. Although woody plants can also encroach into $C_3$ grasslands, accelerated growth of woody plants caused by higher atmospheric $CO_2$ can create ecological opportunities (Archer et al. 2017). The growth efficiency of $C_3$ plants under elevated $CO_2$ concentrations increases by 20 – 35%, while grasses only increase by around

10%, which favours the growth of bushes over grass (Seebauer et al. 2019). Most woody plants are most vulnerable as saplings and become very resilient to external stress –such as climatic events, fire and browsing- at a certain level of maturity. Increased sapling growth due to high $CO_2$ concentrations increase the chances of woody encroacher saplings to escape this vulnerable phase (Archer et al. 2017).

Increased levels of $CO_2$ can also encourage the fast regrowth of woody plants after the removal of above-ground biomass. Warmer temperatures caused by climate change –and the resulting absence of severe frost- can also encourage the proliferation of bush (O'Connor et al. 2014).

### Changes in the Fire Regime

Fire is a natural phenomenon responsible for the maintenance of the savanna ecosystem. It is a key ecological process regulating vegetation structure and species composition (Nepolo & Mapaure 2012). Fires suppress woody plants and benefit grasses (Roques et al. 2001). They have been used by indigenous communities to renew pasture when enough fuel load and litter accumulated (Sheuyange et al. 2012). The active suppression of fire and overgrazing, which reduces the fuel load, encourages the encroachment of woody species. A lack of intense fires encourages saplings to grow and escape the fire flame zone, after which they are fire resistant (Hare et al. 2020).

## 1.4. Impact

Bush encroachment can fragment landscapes, reduce the carrying capacity of rangelands and lead to habitat loss (Blaum et al. 2007). In wetter areas, reductions in carrying capacity range between 40% and 50%. In arid environments, the carrying capacity declines between 70% and 90% (Dannhauser & Jordaan 2015). The resulting degradation of rangelands can lead to food insecurities and poverty (Lesoli *et al.*, 2013). The sustainability of the livestock sector and production is at risk if bush encroachment is not addressed. Apart from biodiversity, bush encroachment also influences tourism, the hydrology of the region (Hengari 2018) as well as many other factors.

### Negative Impacts of Bush Encroachment

#### Carbon Sequestration

Woody encroachment redistributes carbon among key terrestrial pools. While arid areas are more likely to become net sources of carbon, areas with higher rainfall are more likely to become net sinks (Archer et al. 2017).

The dense bush in Namibia stores considerable $CO_2$. The carbon density of bush follows an S-shape: In the beginning, encroacher bushes take up a lot of carbon before it plateaus, and carbon uptake becomes zero. A study by Scholes et al., suggests that many Namibian sites have reached their peak carbon sequestration, but that there is considerable room for expansion into other areas. The high uptake of carbon is likely to make Namibia a net sink for greenhouse gases, although it is considered unsustainable due to the impacts of bush encroachment outlined in this section (Scholes et al. 2005).

Savannas store almost double the soil organic carbon stored in biomass. If bush biomass is fully matured, they reach an equilibrium where changes in carbon are mainly caused by new encroachment in other areas. Soil organic carbon decomposes slowly and can take several decades (Seebauer et al. 2019).

### Hydrology

Woody encroachment can influence runoff, precipitation, deep drainage and evapotranspiration and thus all components of the water budget. Woody plants use water from deeper soil layers and have long periods of transpiration, which reduces underground water levels, which is a critical source of water in Namibia. Woody plants have a higher air turbulence and lower albedo increasing their potential evapotranspiration. They also have a higher canopy interception of rain. The impact of woody encroachment is the greatest where the potential evapotranspiration equals total precipitation (Archer et al. 2017).

A study conducted in Australia suggests that bush encroachment can influence both infiltration and runoff, key processes responsible for the distribution of rainwater in drylands (Eldridge et al. 2014). Runoff can be influenced by changes in the soil infiltration rate caused by woody encroachment (Archer et al. 2017). The impact of bush encroachment on the hydrology will depend on the proportion of shrub and grass canopy and the interspace. Bush encroachment impacted the amount and spatial distribution of infiltration and unvegetated interspaces arrangements thus impacting the water balance of the ecosystem (Eldridge et al. 2015).

### Biodiversity

Woody encroachment can be transformative shifting landscapes from grassland to shrub or tree savannas and these savannas to woodlands or shrublands. As a result of woody encroachment worldwide, grassland ecosystems are endangered in many parts of the world. This shift also causes species adapted to grasslands to be replaced by species adapted to woodlands or shrublands. Although this may increase the overall diversity of species, it may displace species endemic to savanna or grassland ecosystems (Archer et al. 2017). The most damaging species are those that transform ecosystems by changing the disturbance regime: They often use large amounts of resources such as light, water and nutrients and can change the food web and habitats, thus often reducing the abundance of other plants (Lesoli et al. 2013).

The selection of habitats by herbivores is influenced by forage quality and availability, as well as habitat structure which can be impacted by bush encroachment (Schwartz et al. 2017). Woody encroachment can create monocultures decreasing the overall diversity of plant species (Archer et al. 2017). Generally, woody encroachers can impact functional groups, species abundance and evenness of the herbaceous layer even if there are no clear changes in species richness. Changes in the species composition of vegetation can have considerable impacts on ecosystem processes including trophic pyramids, primary production and nutrient cycling. These changes in vegetation can reduce the quality and quantity of habitats for wildlife. The distribution and abundance of many grassland species has declined throughout the world. Some taxa are more sensitive to structural changes than others (Archer et al. 2017).

Different studies elude on the detrimental impact of woody encroachment at higher densities on the abundance of small carnivore species native to the Kalahari (Blaum et al. 2007). Larger bush encroached areas also have a lower diversity and abundance of mammals and birds (Blaum et al. 2009). In a South African study, bird species richness was shown to peak at intermediate bush densities. In areas with denser thickets some open-habitat species disappeared (Sirami et al. 2009). In a Namibian study accounting for the entire aridity gradient, bird species richness was lower in bush encroached thickets than grassy habitats (Hoffman et al. 2010). In central Namibia, lizard species richness declined in dense bush habitats relative to open habitat. Only one species was observed in larger numbers in bush encroached areas (Meik et al. 2002). Results from the BIOTA long-term studies show that although the responses of animal groups vary between taxa two major patterns are evident. Species richness of grasshoppers, reptiles, and rodents declined with shrub cover while spiders, beetles, and carnivores exhibited bell-shaped responses to shrub cover. Species richness was maximised at shrub cover values between 12 and 18% (Hoffman et al 2010 p.49).

Apart from having detrimental effects on grazers due to the suppression of grasses, very high bush densities can also have detrimental effects on browsers (Smit 2004). Woody encroachment can reduce the reproductive success and survival, change predation patterns, encourage parasitism and alter the availability, type and abundance of food resources for both grazers and browsers (Archer et al. 2017).

### Soils

Soil organic matter and soil organic carbon bind nutrients and water and are thus closely linked to soil fertility. Woody encroachment and the resulting increases in biomass can change soil microbial communities and slow decomposition ratios and thus soil fertility. Bare areas between bushes in encroached landscapes can also lead to soil erosion created by wind (Seebauer et al. 2019).

### Economic and Social Impact

Many savanna ecosystems have a limited water availability and woody thickening is considered a key threat to herbaceous plants. The grazing capacity in many Southern African countries has considerably declined making livestock production economically unviable in many areas (Smit 2004).

Bush encroachment makes land inaccessible for livestock and has negative effects on the use of rangelands. The competition for light, nutrients and water by woody plants reduces the capacity of rangelands. The degradation of rangelands can have considerable impacts on food security and poverty levels (Lesoli et al. 2013).

Apart from the potential negative impact on the diversity of wildlife and plants, bush encroached landscapes are often less aesthetically pleasing and have a reduced aesthetic value for tourism (Lesoli et al. 2013).

## Positive Effects of Woody Encroachment

Woody plants can also have a positive impact on the ecosystem. They create unique and diverse habitats and provide browse for livestock and wildlife (Smit 2004). Open savanna landscapes with islands of dense thickets may have the highest overall biodiversity. Namibia generally has soils with a low fertility and low soil organic carbon limiting vegetation growth and agriculture (Hengari 2018). Trees can have a positive impact by enriching the soil under their canopy. Some desirable grasses are positively associated with tree canopies and they provide an important sub-habitat for different species (Smit 2005). However, trees in lower densities often have better browse and leaves can maintain younger phenological states for a longer time (Smit 2004).

The nutrients available to plants are higher in encroached landscapes due to the nitrogen fixing ability of bush with their deep roots. Soil organic matter and soil organic carbon are created through decomposition of organic matter. A lack of these organic inputs from wood, leaves and roots can considerably reduce soil fertility (Seebauer et al. 2019).

Soil hydraulic properties impact the water holding capacity of the soil and plant available moisture. Infiltration of rainwater is highest close to the canopies of woody plants, due to the plant litter underneath the canopy creating higher levels of organic matter and nutrients. In addition, the extensive distribution of roots creates macropores, which have a positive effect on infiltration (Eldridge et al. 2015).

In addition, woody encroachment can increase primary production and carbon sequestration in some cases and promote land-uses using the woody biomass for commercial purposes. The woody biomass may thus become an economic opportunity, diversifying the economy and generating income (Archer et al. 2017).

# 2. Bush Removal – What Then?

## 2.1. Ecological Response of Bush to Harvesting

A key response to woody encroachment is the removal or thinning of woody plants to restore the savanna ecosystem (Smit 2004). Even with reduced stocking rates, farmers are unable to reverse the trend of bush thickening (Van Eck & Van Der Merwe 2004). As a result, farmers in central and northern Namibia started to mitigate the problem by mechanically removing the bushes with saws, axes or bulldozers. However, many woody encroachers do not die after being mechanically removed and strongly regrow from the roots (Strohbach 1998). Especially *Acacia mellifera* can survive felling treatments and must be removed to a 20m depth to remove “sleeping buds” at the base (Strohbach 1998).

Savannas characteristically have a shrub or tree overstory with a herbaceous understory. Species properties, biological interactions and physical determinants interact with each other. Management interventions over time have changed these landscapes at different levels. Thus, the removal of woody plants can have unique impacts in different areas, and these can be both negative and positive (Smit n.d).

Using chemical or mechanical measures to remove woody plants will immediately change the composition of the savanna and competition between grasses and woody plants (Smit 2004). Directly after the removal of bush, there is often a flush of grass growth. The flush of grass after the removal of bush is mostly short-lived and less nutritious forms of grass species tend to grow from the second year onwards due to an absence of organic material from bushes. The increase in soil fertility caused by decomposing roots directly after harvesting is followed by a decline in soil fertility due to a lack of sustained organic inputs (Zimmermann et al. 2017). In a survey conducted by Honsbein (2015), most farmers indicated an increase in grass after bush control. However, the quantity and quality of grass was not better in the long-term (Honsbein 2015). The gaps created by thinning either lead to the development of new woody plants or accelerate growth of neighbouring individuals. Studies on *C. mopane* in South Africa showed that it takes mopane trees around 14 years to return back to the pre-cleared competitive ability through seedling establishment and a total of 40 years to reach the pre-cleared density (Smit 2004).

Namibia is characterised by poor soils and low soil fertility. The removal of woody plants further removes nutrients from the soil, which are lost when products are sold off the land. This can have detrimental effects on soil fertility, as bush can improve soil fertility by decomposition of leaf fall, providing food for termites, improving nutrient cycling and releasing nitrogen and phosphorus from the fine roots contributing to improved soil carbon. The even lower fertility soils after bush harvesting can encourage the re-encroachment of woody plants, while more fertile soils encourage the growth of grasses (Zimmermann et al. 2017).

Especially large trees contribute to the stability of savanna ecosystems leading to soil enrichment, the provision of sub-habitats and suppressing the establishment of woody seedlings (Smit 2004). They serve important functions in savanna ecosystems and are focal points for animal activity by providing food, shade, nesting sites or perches. Animal activity and defaecation also increases the available nutrients for plants. The removal of large trees can change the structural diversity of the landscape and can negatively impact species diversity (Tews et al. 2004). A study by Smit (2005), showed that the removal of all mopane trees caused rapid re-encroachment, while selective thinning and leaving larger trees in the landscape can enrich the soils and provide browse, thus contributing to a stable ecosystem (Smit 2005). Once large trees are lost, unstable ecosystems must be managed, which requires continuous efforts to avoid more threatening species to establish themselves (Smit 2004).

A balance between reducing the competitive effect of woody plants on grasses while maintaining positive impacts of trees must be found (Smit 2004). Ideally bush control should shift the competition between undesired and desired species to ensure grasses and palatable species regain their competitive advantage (Lesoli et al. 2013). In wetter environments more trees can be maintained without affecting the herbaceous layer (Smit 2004).

## 2.2. Importance of Post-Harvest Treatment Plans

Creating a balance between woody vegetation and grasses to ensure the ecosystem is managed sustainably has become a key concern in many rangelands. Apart from the implications of woody encroachment on livestock production, it also influences various other ecosystem services (Archer et al. 2017).

In lands primarily used for livestock production, woody encroachment reduces the availability of valuable forage resources, improves the habitat for parasites and complicates animal handling (Archer et al. 2017). As a result, areas were extensively managed to reduce woody encroachment creating a complex landscape with areas experiencing woody encroachment and areas managed to reduce woody encroachment. In recent years, recovering grassland biodiversity has become more and more important. Thus, distributing woody encroachment treatments over time to create mosaics of different vegetation patterns (structure, age distribution, shapes and patch sizes), diverse habitats and improve biodiversity have become an important management consideration (Archer et al. 2017).

Worldwide, land managers have experienced increasing forage production following the removal of woody plants. However, these positive effects were mostly short-lived and only persisted for 5 to 7 years (Archer et al. 2017). The decline of grasses sometime after the harvesting of bush is driven by the re-establishment of bush and resource availability including water, light and other soil nutrients. Bushes re-establish themselves since most bush control measures only kill the top part of the plants but fail to kill the entire plant and seeds. The release of competition once bushes are removed can stimulate seedling establishment and sapling growth. Post-harvest treatment of woody plants after harvesting is vital to maintain the herbaceous layer and a low woody biomass in the long-term. This provides the basis for "Integrated Brush Management Systems", that consider the timing of initial control and follow-up treatments (Archer & Predick 2014).

Integrated control of woody encroachment often involves various preventive and restorative control measures including chemical, mechanical and biological control. Success of these programmes depends on the understanding of the causes of bush thickening and hindrances to the natural recovery of the ecosystem. This involves having a clear objective of the future status of the ecosystem and should consider costs and benefits. The objectives may differ: Landowners may be interested in increasing livestock production, while policymakers may focus on environmental preservation. Control and post-harvest measures must consider the characteristics of the ecosystem and the stage of encroachment. Bush thickening can be distinguished into four phases: entry or arrival, establishment and adaptation, exponential growth and dominance. Options for controlling bush thickening at the final stage are extremely limited (Lesoli et al. 2013).

The thickening of woody plants is a continuous process in savannas. Thus, it cannot be controlled by a single bush control operation but requires continuous planning and implementation to effectively ensure the stability of the ecosystem. In areas with very high densities, a first drastic thinning measure will be necessary before a post-harvest treatment programme can be implemented to ensure the area remains open (Smit n.d; Lesoli et al. 2013).

Some measures can only be used at a certain stage of encroachment or leave landscapes vulnerable to other disturbances if left untreated. For example, fire can kill shoots but the seeds in the soil may be stimulated to germinate. In this case, biological control measures should be added to control re-encroachment (Lesoli et al. 2013). Bush control programmes should be based on the causes for bush proliferation, the response of targeted species on different control measures and the effect on the current land use (Dannhauser & Jordaan 2015). In addition, prior to any bush control measures a post-harvest or post-encroachment strategy should be developed. The removal of woody plants can leave the land vulnerable to erosion or re-encroachment independent of the method used. Performance measures should be defined and monitored. Adaptive management is a key component in ensuring the status and trends are monitored and decisions are adapted to create a balance between ecological, economic and social objectives. Throughout the implementation of bush thinning and post-harvesting measures, the ecosystem's performance should be evaluated, and a sustainability management programme should be implemented to eliminate factors that caused encroachment in the first place (Lesoli et al. 2013).

The first step towards developing a post-harvest treatment plan should be a detailed assessment of the land and its resources to define the nature and the extent of the problem (Smit n.d.). This includes the identification of encroaching species, their physiology, morphology, anatomy, phenology and how they spread. In addition, their density and spatial distribution should be assessed and if there are any seasonal variations. Thereafter, their impact on the ecosystem can be established based on primary and secondary productivity and ecosystem stability by looking at soil cover and biodiversity (Lesoli et al. 2013). In addition, soils and their potential should be assessed. This ensures that areas that require treatment are identified and areas that do not qualify are excluded. For example, areas that naturally have a high density of trees, very steep areas, areas with a limited potential for production and mountainous areas are excluded due to the high costs involved, ecological considerations or the limited potential of the land. Land managers must distinguish between areas where trees must be removed and areas where other measures can control further thickening. Land-use decisions will further influence bush control and measures used (Smit n.d.).

Based on economic and environmental assessments, very few attempts to restore savanna ecosystems have been successful in Southern Africa (Smit 2004). There is no quick solution to addressing woody encroachment and it requires a long-term commitment (Smit 2004). For example, coppicing is a big problem with *Terminalia sericea* and *Dichrostachys cinerea* and can only be controlled by removing coppice at least four times a year (Strohbach 1998).

Due to the impact of bush encroachment and the necessity of post-harvest treatments to ensure restoration benefits, it becomes an important topic in the context of international agreements such as the UNCBD, UNCCD and the UNFCC / Paris Agreement ratified by

Namibia. As part of the country's commitment to reduce greenhouse gas emissions, the variation in carbon emission and sequestration rates following bush thinning under scrutiny. An analysis of the carbon sequestration potential of a "Savanna Restoration" scenario with aftercare increased carbon sequestration when harvesting 50% of the biomass. The increase in soil organic carbon through grassland restoration interventions can even offset emissions from increasing livestock densities. Under a bush farming scenario soil organic carbon was maintained at a constant level (Seebauer et al. 2019).

Improved decision-making should consider questions at the systems level including ecological and economic components (Lesoli et al. 2013). If the economic assessment of managing woody encroachment is only based on improving rangeland without considering other ecosystem services, it will most likely not be economically justified. However, if all ecosystem services are considered the cost-benefit assessment will change (Archer et al. 2017). Conservation of biodiversity and the stability of rangelands by restoring the health and resilience of the ecosystem can ensure the provision of ecosystem services in the long-term. These vital ecosystem services include the supply of water, stable and fertile soils, and the occurrence of animals, plants and other organisms for aesthetic and cultural purposes and to enhance livelihoods (Lesoli et al. 2013).

### 2.3. Current Post-Harvest Treatment in Namibia

Based on a survey conducted by Honsbein on behalf of the De-bushing Advisory Service (DAS) in 2015, only a tiny fraction of farmers conducted aftercare or post-harvest treatments. The majority of famers that conduced aftercare were commercial farmers. Honsbein suggested that the share of commercial farmers is higher since aftercare is considered very costly. Manually sprayed arboricides (18,3%) were the main measure used for the post-harvest treatment of bush, followed by manual cutting (14,3%) and very small shares of burning (5,6%) or browsing (1,6%) (DAS 2015).

## 3. Post-Harvest Treatment Measures

### 3.1. Objective 1: Restoration (to include national and international practices)

## Fire

### Description

Fire is a natural phenomenon responsible for the maintenance of the savanna ecosystem. It is a key ecological process regulating vegetation structure and species composition (Nepolo & Mapaure 2012). A fire regime includes the frequency, intensity and seasonality of fire. The intensity is one of the most important components of the fire regime. The heat generated by burning biomass triggers an oxidative process releasing carbon compounds as heat. The rate at which a fire burns depends on the vertical level at which energy is released, fuel load and moisture. The vertical level determines at what height plants are burned and their chances of survival. For taller woody plants higher fire intensities are needed to top kill the plant (Lesoli et al. 2013).

### Options

1. **Veld Fires:** There are different types of fires. Ground fires burn low on the ground and are spurred by debris and organic material. This type is rare and mostly restricted to forest ecosystems. The most common fire in grasslands is surface fire burning in the herbaceous layer. They can turn into crown fires by igniting the foliage of trees and shrubs. This often requires favourable conditions such as a low humidity, high temperatures and high winds. In addition, fires can be further subdivided into head fires (burning with the wind) or back fires (burning against the wind). Head fires reach higher temperatures above ground level and are more intense than backfires. They often release heat far above the ground by burning foliage. Backfires are hotter, but the heat is confined to the soil surface. Head fires are heavily influenced by the atmospheric conditions. Controlled burns of encroachers should be a head fire, because they maximise damage to woody plants and minimise damage to the grass layer (Dannhauser & Jordaan 2015).
2. **Stem Burning:** The use of a small, low intensity fire around the stem of the woody encroacher allows to selectively kill trees. The long application of heat can severely damage the bark and buds and can eventually kill the tree. It is not well suited for multi-stemmed species or trees with small stems (Smit n.d.).

### Context

Traditionally, fire was used when sufficient fuel loads of grass and woody litter accumulated, to improve the quality of the pasture. A study by Sheuyange et al. suggests that woody plants were reduced, and grass cover was higher in recently burned landscapes (Sheuyange et al. 2005).

### Synergies

Different authors suggest that fire should be followed up by browsers (Joubert et al. 2012; Lesoli et al. 2013). In a study in Ethiopia, stump deaths of *Acacia mellifera* and *Acacia reficiens* were the highest with a fire-browse combination (Hare et al. 2020).

### Preconditions

Fire cannot always be applied and depends on the ability of the ecosystem to support fire. A high intensity fire is required to control bush seedlings, coppice or maintaining woody plants at a specific height for the use of browsers. Fire is better suited for areas with considerable rainfall and good soil moisture to support sufficient fuel load for regular fires. The use of fires must be sustained with periodic follow-up burns (Lesoli et al. 2013).

An intense fire is needed to control woody encroachment. According to Dannhauser & Jordaan, this requires about 3000 kg/ha of grass fuel load. The air temperature should be higher than 25°C and humidity lower than 30%. The fuel load must be dry and wind must come from the right direction and not exceed 5.6 m/s to ensure the fire can be controlled (Dannhauser & Jordaan 2015). Joubert et al. suggest a fuel load of 2000 kg/ha (Joubert et al. 2012). The most important precondition is that the grass must still be dormant (Dannhauser & Jordaan 2015).

Areas treated by fire attract animals and should be protected from continuous grazing. This can be achieved by moving livestock from one camp to another on a rotational basis. It could also be addressed by burning several areas and stocking with browsers to limit regrowth (Van Oudtshoorn 2015).

| Advantages + | Disadvantages − |
|---|---|
| • Fire can clear litter allowing light-demanding species to gain a competitive advantage and increases the soil temperature triggering the release of nitrogen from organic matter (Nepolo & Mapaure 2012).<br>• Fire can enhance the growth of herbaceous plants by removing inhibitors and replacing un-palatable species by palatable species (Nepolo & Mapaure 2012).<br>• It plays a role in seed germination and synchronising flowering (Nepolo & Mapaure 2012).<br>• Fire can have a considerable impact on the seedlings, growth, survival and adult recruitment of woody plants (O'Connor et al. 2014). | • Reducing woody plants by burning can have positive effects on grasses. However, the lower bush densities also reduce the basal cover required by herbaceous plants. This can create risks of soil erosion (Lesoli et al. 2013).<br>• In landscapes regularly affected by droughts, the accumulation of sufficient fuel load for fires can often only be achieved by reducing livestock numbers in the area landowners wish to control through burning (Lesoli et al. 2013).<br>• Fires are often not able to kill woody plants in Southern African savannas, which have been subjected to fire for decades but can be useful to modify the structure of the woody layer (Smit n.d.). However, Joubert et al found a significant mortality rate of *A. mellifera* seedlings in arid Namibian savanna (Joubert et al. 2012). Some species may even be encouraged to germinate e.g. *Dichrostachys cinerea*.<br>• Burning can cause nutrient losses in the soil and affect small animals (Joubert et al. 2012).<br>• Considerable knowledge about fire is required. Burning at the wrong time with the wrong objectives can lead to soil erosion, rainwater runoff and reduce basal and grass cover (Dannhauser & Jordaan 2015).<br>• The area burnt must be left untouched for a certain amount of time before it can be productive again, a full season or more. (Van Oudtshoorn, 2015).<br>• If uncontrolled, fire can damage the property of neighbours.<br>• Diesel is often used to ignite fires, which can have negative environmental impacts (SoK Workshop). |

| | |
|---|---|
| Effectiveness | In a Namibian burning experiment, a single moderate fire killed up to 99% of *S. mellifera* seedlings in a semi-arid savanna (O'Connor et al. 2014). Decreases in productivity following a controlled burn are compensated by the higher production of grasses in the long-term (Hoffmann et al. 2010). Larger stems are heat sinks and may thus suffer less xylem damage. However, larger shrubs have a slower growth rate after the burn (Joubert et al. 2012). In a study conducted in Ethiopia, stem burning was identified as the most efficient killing 98,8% of *Acacia mellifera* (Hare et al. 2020). During the SoK workshop, stakeholders pointed out that fire is more effective to control saplings and seedlings. |
| Timing | Naturally, fires occur every 1 to 5 years in wet savannas, where a high fuel load is available (Nepolo & Mapaure 2012). Depending on the frequency of recruitment, burning once every 20 years may be sufficient to control bush (Hoffmann et al. 2010). FSC suggests the use of fire every 5 years (SoK Workshop).<br><br>Generally, the frequency of fire depends on the accumulation of sufficient fuel, which is influenced by grazing and general conditions for plant growth such as rainfall (Dannhauser & Jordaan 2015). To minimise soil erosion, the time between burning and grass growth should be as short as possible. The fire should thus be applied close to the beginning of the growing season. Dannhauser & Jordaan indicate a 6-week time frame for burning: Burning should take place earliest four weeks before the growing season and latest 2 weeks into the growing season (Dannhauser & Jordaan 2015). |
| Costs | Fire is the cheapest measure. However, the effectiveness of fire depends on a well-informed and clear fire regime adapted to the natural ecosystem (Lesoli et al. 2013). Stem burning is considered inexpensive, but very time consuming and labour demanding. |

## Biological Control

### Description

Biological control measures use living organisms to reduce the reproductive capacity, growth and effects of woody plants (Lesoli et al. 2013). The loss of mega-herbivores can partly be compensated by farming with goats, sheep and wildlife (Honsbein 2015). Biological control can also involve the introduction of invertebrates or diseases. The main aim of biocontrol to ensure a woody species is still able to reproduce and grow but does not aggressively colonise. Lesoli et al. consider biological control the *"only sustainable mechanism to prevent the spread of invasive (...) species in the long-term"* (Lesoli et al. 2013).

### Options

1. **Wild Herbivores:** Browsers can either be used to control woody plants or use the forage produced by woody biomass in the long-term. The complete control or elimination of woody plants cannot be achieved through wildlife except for the elephant (Smit n.d.). Wild browsers and other seed predators can prevent woody encroachers from establishing, proliferating and keep them at a state where they are vulnerable to fire thereby supporting the maintenance of savanna and grassland systems. Maintaining native browsers can thus balance woody-grass

vegetation, enhancing biodiversity and creating economic opportunities around consumptive and non-consumptive utilisation of game (Archer et al. 2017).

2. **Boer Goats** can successfully control woody encroachment, because the intensity and frequency of their browsing can be managed. They are also insensitive to the high levels of chemical deterrents (e.g. tannin) in woody plants (Smit n.d.). Some *Acacia* species are more resistant to the impact of goats (Van Oudtshoorn 2015). Goats tend to avoid *Acacia mellifera* but can be used to control other species for example *Dichostachys cinerea* (Joubert et al. 2012).
3. **Invertebrates:** The seed-feeding weevil has been used in South Africa to control *Acacia mearnsii* (Lesoli et al. 2013). In addition, other insects have been successfully used to control *Acacia* spp. and *Sesbania punicea* (Dannhauser & Jordaan 2015). Used together with plant-attacking biocontrol agents they completely kill the plants and should not be used if the wood is to be used for commercial purposes. The impact of biocontrol on encroacher bushes depends on the biological agents, their mode of operation and the target species that should be controlled (Lesoli et al. 2013).
4. **Fungi** can cause the yellowing of leaves, defoliation and the death of shoots in the first phase before causing the complete death of blackthorn (Phase II: Decline). The plant dies within the next 2 – 3 years and it takes a total of 4 – 6 years before the stands open. The study predicts that the area will stay clear of blackthorn for 2 – 3 decades (Van der Merwe 2007).
5. **Trampling:** This method is only suitable for smaller shrubs to maintain open grasslands after initial control. Large herds of grazers can be used to trample and graze the area for a short period of time after which the land must be allowed to rest. Due to the trampling, more light is available for the herbaceous layer and urine and dung are deposited on site. It can give grasses a competitive advantage over woody plants who are less adapted to trampling. To achieve the desired effect, about 150 AU/ha/day are needed and can be guided by movable electric fencing (Van Oudtshoorn 2015).
6. **Wild Hares:** During the Stakeholder Workshop on the State of Knowledge Report it was mentioned that some farmers believe that wild heirs successfully control coppicing after initial bush control – especially if used together with goats. Peter Cunningham noted that these are specifically *L. capensis* and *L. saxatilis* who feed on seedlings.
7. **Parasitic Plants:** Some parasitic plants spread by birds can infest large areas and cause dieback in woody plants (SoK Workshop.

**Context Used**

Biological control is mainly used to prevent bush encroachment or for post-harvest treatment of woody plants. Mechanical, chemical bush thinning, or fire are often more suited for the initial removal (Smit n.d.).

**Synergies**

Combining herbicides and biological control agents can successfully control encroachment: Herbicides can be used to contain the infestation, while invertebrates control the plants and goats kill the coppice (Lesoli et al. 2013).

Biological control is the most effective if combined with fire (Joubert et al. 2012, Lesoli et al. 2013). Fire can be used to reduce the browse level to make it available for goats. A fuel load of more than 2500 kg/ha would be required to achieve the desired intensity (Van Oudtshoorn 2015). In a study in Ethiopia, stump deaths of *Acacia mellifera* and *Acacia reficiens* were the highest with a fire-browse combination (Hare et al. 2020).

**Preconditions** Goats can only be used in areas with low canopies (1.5m and below). Otherwise mechanical, chemical control or fire must be used to achieve the right canopy heights (Smit n.d.).

The species that should be controlled must be part of the diet of goats and sufficient browse material must be available. If the controlled species is not preferred by browsers, invertebrates could be used as biological control agents (Lesoli et al. 2013).

The stocking rate of goats must be high enough to control re-encroachment. Van Oudtshoorn suggests that goats should be kept at stocking rates of one goat per hectare to create the required browsing pressure (Van Oudtshoorn 2015).

**Advantages**

- Insects used as biocontrol agents can survive in the treated area for a long time and can re-establish themselves should the tree density increase again (Lesoli et al. 2013).
- They are mobile and actively look for new target plants (Van Oudtshoorn 2015).
- Biological control agents can be a very inexpensive and environmentally sound measure if biocontrol agents are carefully screened. "Host shifts" have not been recorded in over 350 cases using biocontrol worldwide (Lesoli et al. 2013). Thus, they are host-specific only controlling targeted species (Van Oudtshoorn 2015).
- Browsers such as goats can be a profitable enterprise, offsetting initial bush control costs. The costs of the bush control programme can also be lowered (Van Oudtshoorn 2015).
- Biocontrol can reduce the photosynthetic surface, destroy reinforcement tissue and transport systems of the plant, cause disease and create pathways for pathogens, inject toxic substances and divert nutrients. They can also destroy seeds and prevent seed production (Van Oudtshoorn 2015).
- Studies on fungi predict that the area will stay clear of blackthorn for 2 – 3 decades (Van der Merwe 2007).

**Disadvantages**

When browse becomes scarce, goats start to eat grass. Diet overlaps with grazers must be considered. In areas where goats were heavily stocked the herbaceous layer was severely damaged. Goats are thus less useful in areas that have a reasonable grass component (Smit n.d.).

- Goats require very high levels of management: If they can range freely, they are unlikely to exercise the browsing intensity required to control woody plants. They must be kept in the area long enough (Smit n.d.).
- Special infrastructure (fences, etc) is needed (Van Oudtshoorn 2015).
- Often not all target species can be controlled, (especially spinescent *Acacia* species are resistant) (Van Oudtshoorn 2015).
- It may be difficult to get hold of some biocontrol agents such as specific invertebrates (Lesoli et al. 2013).
- Insects and fungi need to get past phytosanitary controls, which can make it a long process (SoK Workshop).
- Beetles could make crossbreeds that could be very damaging to desirable plant species (SoK Workshop).

**Effectiveness**

Goats can effectively eliminate mature bush especially in conjunction with burning. In a Namibian trial, this combination reduced bush density by 60% within 40 years (O'Connor et al. 2014). Stocking goats can prevent the re-encroachment of bush after harvesting (DAS 2015). A study by du Toit proved that intensive and frequent browsing by goats can kill 63% of *Acacia karroo* coppice, reducing coppicing to 28% of areas where coppice was not controlled by goats (Smit n.d.).

In the Kruger National Park in South Africa, *Salvinia molesta* or kariba weed was successfully controlled with *Cyrtobagous salviniae* (snout beetle). *S. molesta* was brought under complete control and maintained at that level. *Sesbania punicea* (Red Sesbania) at Kruger National Park was controlled with three weevil species (*Trichapion lativentre, Neodiplogrammus quadrivattatus, Rhyssomatus marginatus*) and was considered as *"the best example of an invasive tree species control"* (Lesoli et al. 2013).

| | |
|---|---|
| Timing | Anytime if sufficient forage is available. |
| Costs | Inexpensive depending on the availability within the country and region. |

## Mechanical Control

**Description**

Mechanical control involves damaging or completely removing woody plants with specialised equipment or machinery (Dannhauser & Jordaan 2015, Van Oudtshoorn 2015). It includes slashing or chopping, uprooting or ring barking targeted plants (Dannhauser & Jordaan 2015).

**Options**

1. **Pulling & Cutting:** Manual methods are mainly used to control woody plants in very small areas. These measures are very selective and minimise damage for desirable plants but are time and labour intensive and must be conducted several times to ensure minimum re-encroachment (Lesoli et al. 2013). The main tools used are pangas, axes, chain saws, hand saws and brush cutters Machines or labourers may disturb the soil and trample vegetation supporting re-encroachment (Van Oudtshoorn 2015).
2. **Bulldozers:** In larger areas, bulldozers uprooting the entire plant are used. This minimises re-sprouting, but the soil disturbance erodes the grass layer encouraging re-encroachment through the establishment of seedlings. The result may be even denser encroachment than before (Lesoli et al. 2013).
3. **Rolling:** A large roller (weighing several tons and several meters wide) is mounted in front or towed behind a tractor, crushing and cutting bush.

**Context Used**

Mechanical control can be used after a chemical or mechanical thinning interventions. For small areas, hand methods are ideal. Rolling requires relative flat areas with smooth surfaces.

**Synergies**

Mechanical control is mostly used in conjunction with chemical and biological control measures (Dannhauser & Jordaan 2015). Coppice can be well controlled by goats (Strohbach 1998). Hare et al. indicate that mortality of woody plants is considerably higher if mechanical control is used in conjunction with fire and browsing increasing mortality of *Acacia mellifera* from 55% to 95%

(mechanical control with fire and browsing) and 90% (mechanical control with fire). Coppicing was best controlled in their mechanical control with fire and browsing scenario (Hare et al. 2020).

**Preconditions**

The land has to be accessible for the machinery and the right equipment must be available.

**Advantages**

- No herbicides / arboricides used
- It can create job opportunities (Van Oudtshoorn 2015)
- Small-scale methods are selective and only undesirable plants are removed (Van Oudtshoorn 2015).
- The cut wood can be used in the control programme (see soil enhancement below) or different value chains (Van Oudtshoorn 2015)
- Although mechanical control can cause soil compaction, some machinery can also loosen up compacted and degraded soils (SoK Workshop).

**Disadvantages**

- Mechanical control of woody encroachment with heavy bulldozers can compact soils and cause considerable soil disturbance, which will impact the herbaceous layer and grasses must completely re-establish themselves on the bare soil. Disturbance can also encourage the establishment of encroachers (Smit n.d.).
- Selective mechanical control can be very time consuming and the collection and disposal of the cut wood often requires extra labour (Van Oudtshoorn 2015)
- Machines or labourers may disturb the soil and trample vegetation supporting re-encroachment (Lesoli et al. 2013).
- The mortality of coppicing plants is low (Hare et al. 2020).

**Effectiveness**

A study by Hare et al 2020 in Ethopia suggests that mechanical control causes a 55% mortality of *Acacia* mellifera, but that it promoted stump coppicing (Hare et al. 2020). Annual grasses with a low forage value tend to establish themselves first. In addition, the severe disturbance to the soil encourages the establishment of woody plant seedlings promoting regrowth at even higher densities than before (Smit n.d.). Removing coppice must be done 3-4 times annually for up to 2 years after bush control (Strohbach 1998).

**Timing**

Anytime. To damage the plant and reduce re-sprouting, treatment in the late growing season may be best (Hodel & Pittenger 2002).

**Costs**

It is labour intensive and thus can be quite expensive (Lesoli et al. 2013). Rolling seems to be the most cost-effective method with N$ 308/ha from (Internal Nampower Report).

Manual Weeding: The costs of "weed control" are probably less than N$150/ha (Rothauge 2019).

## Chemical Control

**Description**

Herbicides have different chemical properties which make them applicable for different soils, climates, application options and effects on the environment (Lesoli et al. 2013).

**Options**

1. **Soil Applied Herbicides:** Herbicides that are applied to the soil and absorbed by the roots are mostly based on bromacil, tebuthiuron or ethidimuron. Concentrations between 20% and 70% are available in the form of granules, liquid or a wetable powder (Lesoli et al. 2013). They are mainly applied by hand to the soil around the stem of the plant. Water infiltrating the soil dissolves the chemical and transports it to the root zone (Van Oudtshoorn 2015). Some can be used for aerial application (Lesoli et al. 2013). Bromacil affects the photosynthetic pathways of plants and inhibits photosynthesis causing *"chloroplast swelling, membrane leakage, and ultimately cellular destruction"*. The plant dies by slow starvation (Lesoli et al. 2013).
2. **Plant Applied Herbicides:** Herbicides that are sprayed onto the plant and absorbed by the foliage or other parts such as stems are mainly based on picloram, 2.4-D and 2.4.5-T (Lesoli et al. 2013). They can be applied selectively by hand or unselectively through aerial spraying (Van Oudtshoorn 2015). This includes Basal Stem Application, where the lower 30cm of the stem and uncovered roots are treated, and Frill Application, where the chemicals are applied to cuts created by an axe (Van Oudtshoorn 2015).
3. **Cut Stump Application** normally takes place directly after mechanical control when the stumps are freshly cut (Van Oudtshoorn 2015).

**Context Used**

Most chemical control measures are expensive and primarily used for the initial thinning of high-density bush to selectively kill individuals, when there is insufficient fuel load for fire or trees are above the browse line of goats. However, they sometimes be used for post-harvest treatments for example after fire to kill seedlings (Lesoli et al. 2013).

**Soil Applied Herbicides** are unselective and can kill unwanted species. They are thus mainly used in areas where unwanted species dominate. The transportation with rainwater to the root zone is more effective in sandy soils. In clayey soils, higher concentrations of the chemicals are required (Van Oudtshoorn 2015).

**Plant Applied Herbicides:** Frill Application is often used in close proximity to water bodies to avoid risking chemical runoff (Van Oudtshoorn 2015).

**Synergies**

Combining herbicides and biological control agents can successfully control encroachment: Herbicides can be used to contain the infestation, while invertebrates control the plants and goats kill the coppice (Lesoli et al. 2013).

**Preconditions**

**Soil Applied Herbicides:** The amount required depends on the pH, organic matter and clay content of the soil. They remain in the soil and are activated by the first rains, which dissolves the active ingredient until it can be taken up by the roots of the woody plants (Lesoli et al. 2013). When the clay content of the soil exceeds 30%, this form of chemical control is considered too expensive. To ensure non-targeted species are not killed, the distance between targeted and untargeted plants should be more than double the height of the of the non-targeted plant (Van

Oudtshoorn 2015).

**Plant Applied Herbicides – Foliar Spraying:** Should only be considered when the plants are smaller than 1.5 – 2 m. Spraying during strong winds must be avoided. Follow-ups are necessary to treat coppicing plants (Van Oudtshoorn 2015).

**Stem Applied Herbicides:** Stems to be treated must be cut cleanly right after being cut and cleaned of any residues or dust before applying the chemical. Follow-up treatments are required to control coppicing (Van Oudtshoorn 2015).

Advantages

+

*Soil Applied Herbicides*

- Trees are rapidly treated, and no mechanical control is necessary (Smit n.d.)
- Seedling regeneration is suppressed for 4 – 5 years (Smit n.d.)
- The small quantities required makes it the most inexpensive herbicide (Smit n.d.)

*Plant Applied Herbicides*

- Can be applied very selectively to ensure other trees or plants are not affected (Smit n.d.).
- Most treated plants are dead right after the treatment, and you can immediately see if the plants are dead (Smit n.d.).
- The material of cut down trees can be used in different value chains to redeem some of the costs of control. The material could also be left on the land to improve the microclimate, protect seedlings, slowing runoff and thus promoting the recovery of grass (Smit n.d.).
- The results ensure an attractive landscape (Smit n.d.).

Disadvantages

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*Soil Applied Herbicides*

- The considerable root network can cause other plants in the vicinity of the treated woody plants to be affected even if the herbicide is applied selectively (Smit n.d.)
- It may take up to 2 years to kill the treated woody plants, because rainwater is needed to carry it into the soil (Smit n.d.)
- The dead trees stay in the landscape to decompose and nutrients cannot be used by other plants. The landscape with dead trees is not aesthetically pleasing and may be unattractive for tourists if this is a key land-use (Smit n.d.). The chemically treated trees must be used for charcoal within one year, thereafter they have no commercial use. Need various methods making it expensive (SoK Workshop).
- If the clay content is higher than 30%, some herbicides are not effective (Lesoli et al. 2013)
- Some trees may survive –especially evergreen trees- and some trees require very high doses of herbicides to die. The required differentiation of treatment for various tree species can make the process complicated (Smit n.d.)
- Chemicals will stay in the soil for several years (Lesoli et al. 2013). Bromacil cannot be absorbed by soil colloids. Leaching of the chemical through the soil can contaminate groundwater. However, it is highly vulnerable to microbial degradation. It persists in the soil for about a year (Lesoli et al. 2013).

*Plant Applied Herbicides*

- The high level of selectivity makes it a very time-consuming operation, labour intensive and the mechanical operations after the chemical control make it expensive (Smit n.d.).

General

- If herbicides are used on forbs, they can considerably impact ecosystems across trophic levels since forbs are important nutrition for wildlife and provide key structural elements (Lesoli et al. 2013).
- Over time, plants may develop a resistance to herbicides and adapt through phenological changes. They can also adapt by changing their relative growth, germination and photosynthetic rate (Lesoli et al. 2013).
- Some untargeted animals and plants may also be exposed to herbicides. This depends on the properties of the chemicals, method of application, amount and frequency of use, weather and the environment (Lesoli et al. 2013).
- The half-life of different chemicals ranges from 1 month for 2,4-D to 3 – 12 months for metsulphuron methyl, trifluralin, atrazine and over 1 year for tebuthiuron, picloram, chlorsulphoron, pendimethalin and ethametsulphuron methyl (Lesoli et al. 2013). The half-life can be extended in dry areas with limited soil moisture and a high soil pH. If used consecutively, residues of the chemicals can accumulate to toxic levels and can have persistent toxic properties (chlorsulphuron and atrazine) (Lesoli et al. 2013).
- Some herbicides may be harmful to humans and other organisms (Van Oudtshoorn 2015; FSc list of hazardous pesticides)
- Old engine oil is often used to save costs and can have detrimental impacts on the environment (SoK Workshop).
- Some active ingredients may be banned in offtake markets. Especially within the EU, there are stringent regulations on traces of chemicals in livestock products (SoK Workshop).

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| Effectiveness | Chemicals can be very effective especially when they are applied to plants that are actively growing or in the late growing season when carbohydrates are translocated to the roots (Van Oudtshoorn 2015). |
| Timing | Chemicals are mainly applied before the active growth phase of the plant and the wet season stabilises (Lesoli et al. 2013).<br><br>**Stem Applied Herbicides** need to be applied to freshly cut surfaces, otherwise they will not be absorbed by the plant. They are advised to be used in the active growing |

| | |
|---|---|
| | season, but good results may also be achieved throughout the rest of the year (Van Oudtshoorn 2015).<br><br>**Foliar Spraying:** Plants should be treated in the growing season to ensure chemicals are readily absorbed. New growth must be above a critical size and must be actively growing (green). Wind conditions must be light to prevent herbicide drift (Van Oudtshoorn 2015). |
| Costs | The use of chemicals is a very expensive measure and should only be considered in specific cases (Smit n.d). Manual foliar spraying costs between N$170 - N$200/ha (Rothauge 2019). Other estimates for foliar treatments range between N$ 600 and N$1200 per hectare, stem treatment being cheaper (Internal Report to Nampower). |

## Measures to Enhance Biodiversity and Soils

### Grass Reseeding or Inter-Seeding

Description

Woods et al. suggest that an effective control must include both top-down and bottom-up control to not just ensure the removal but also the chances of re-growth. Reseeding is used to give native or desired species a competitive edge (Woods et al. 2012). Sowing of perennial grasses can increase competition and reduce bush density more than control alone (O'Connor et al. 2014). In a study analysing the impact of bush control on herbivores, reseeded sites displayed the highest grass cover (Schwartz et al. 2017).

Management practices should consider the maintenance of water-capturing vegetation in interspaces to capture water and improve infiltration (Eldridge et al. 2015). This could be done by grasses, due to their shallow roots.

Options

1. **Seeding:** Seeding practices involve the preparation of a seedbed before seeding or planting desired grasses (Phillips-Mao 2017).
2. **Inter-Seeding:** Inter-seeding into the remaining vegetation after encroacher control avoids soil disturbance. Phillips-Mao (in a guide on how to restore encroached prairies) suggests to widely broadcasts seeds directly to the area following a fire. No seedbed preparation is required but contact to the soil should be maximised (Phillips-Mao 2017).
3. **Supplement in Livestock Feed:** Some farmers add grass seeds to livestock fodder. The seeds are then dispersed by livestock as they feed (SoK Workshop).

Context Used

Thinned areas with relatively fertile soils and some woody plants providing shade and nutrients.

Synergies

To support the establishment and development of seeds, Phillips-Mao suggests using rotational burning to maintain the landscape's diversity and wildlife refuges. While the seeded grass is establishing itself, there should be regular removal of competition through mechanical means or the selective use of herbicides as well as prescribed fire to discourage re-encroachment (Phillips-Mao 2017).

Seeds require some sort of coverage to protect them. Mulch can help to maintain soil moisture, reduce erosion and improve the growing conditions for seeds (Woods et al. 2012).

**Preconditions**

The specificities of the site should be considered when choosing seeds to avoid negative impacts on the remaining vegetation, wildlife and soil communities. Ideally plants already present at the sight should be used and locally harvested seed should be promoted. Species for reseeding could also be chosen based on historical records or reference sites (Phillips-Mao 2017).

The establishment of seeds can take up to 7 years for prairie landscapes. This will depend on factors such as soil moisture, climate and competitive pressure. Aftercare is vital to reduce competition and prevent re-encroachment (Phillips-Mao 2017). In Namibia, this would require research.

**Advantages**

- Broadcasting allows for a wide dispersal of seeds. This also includes sites with difficult conditions e.g. rocky or uneven soils (Phillips-Mao 2017).

**Disadvantages**

- An adequate amount of water is required for seedlings to establish themselves. A lack of water and seedling establishment can have undesirable effects on the landscape e.g. by increasing soil erosion (Woods et al. 2012).
- The seeds of locally adapted grass species are often not commercially available.

**Effectiveness**

Depends on water and seed availability (Woods et al. 2012). Trials must be conducted in Namibia to test the effectiveness under local conditions.

**Timing**

Wet Season

**Costs**

Very low if the seeds can be collected on the farm.

## Soil Enhancement

**Description**

The use of arboricides as post-harvest treatment can limit the restoration of soil fertility. To speed up the restoration of soil fertility, minerals removed through the harvesting of bush must be returned (Zimmermann et al. 2017).

Leaving litter to cover the soil can improve infiltration rates by enhancing the porosity of the soil. It alters the size and density of macropores regulating surface temperature and soil moisture increasing the aggregation of the water table. Improved surface moisture has positive impacts on surface-active and subterranean termites responsible for producing macropores. It can also contribute to reducing overland flow ponding water, reducing runoff and thus the detachment of soil particles (Eldridge et al. 2015).

Options

1. **Brush Packing** is the deposition of branches of cleared bush (usually woody thorn) on thinned areas to promote the seedling establishment and growth of grass. It can restore nutrients and moisture content in degraded soils (Mangani et al. 2018; Meyer 2020)
2. **Wood Ash:** Wood ash is the residue from the burning of organic material and contains most of the trace elements and inorganic nutrients of biomass (Wiklund 2017). The ash from burning woody biomass is widely used as agricultural soil amendment. It can raise the pH of the soil and add nutrients (Saunders 2014).
3. **Wood Acid:** Wood acid is a side-product of charcoal production when the smoke is distilled and left to stand for 3 months to naturally purify. It is used for various purposes including as animal feed supplement, odour remover, insect repellent as well as foliar and soil fertiliser (Mungkunkamchao et al. 2013). Wood acid consists of various acids, compounds and minerals. It can help to protect plants against insects and some plant diseases (Sadakichi & Hirowaka n.d.).
4. **Charcoal:** Charcoal is very porous and thus easily retains moisture. It can improve the soil by increasing water retention and water permeability. It can also increase useful microbes, which encourages stronger root development and can protect plants against insects. It also has some minerals including boron and calcium that can be easily absorbed by plants due to the carbonisation process (Sadakichi & Hirowaka n.d.).
5. **Chemical Fertilisers:** Some Namibian farmers have used chemical fertilisers to improve soil conditions, which improved seedbanks and caused grass to also spread to other areas (SoK Workshop).

Context Used

Using wood ash can compensate for nutrient losses created by the harvesting of woody plants and resulting removal of nutrients (Wiklund 2017).

Synergies

Branches of for example of *Acacia trees* can be left on the land to protect grass seedlings from grazers and to provide fuel for a hot fire after one or two seasons (Strohbach 1998).
Brush packing can be used to support grass growth after re-seeding (Kellner, 2019).

Preconditions

**Brush Packing:** The brush (woody branches/twigs) used should be placed against the flow of water to trap any other organic material and if possible to a height not exceeding 1.5m. Branches should not be stacked on top of each other, but spread evenly over the area for total coverage (Mangani et al. 2018).

Advantages

- Woody ash has considerable amounts of calcium and potassium and smaller amounts of magnesium, phosphorus, zinc and copper -among other micro-nutrients- which are important soil nutrients (Saunders 2014).

Brush Packing:

Disadvantages

- Woody ash should not be directly applied to germinating seeds. The high salt content in the ask could slow their growth (Saunders n.d.).
- Spreading woody ash at a large scale can create a lot of dust (Saunders 2014).

Brush Packing:

| | |
|---|---|
| • Cost-effective and easily accepted by local communities as it doesn't require additional inputs (Sebitloane et al. n.d.).<br>• Brush packing creates a micro-habitat favourable for the recruitment and growth of grasses and protects new seedlings from herbivory (Kellner, 2019).<br>• It decreases soil surface temperatures and improves the soil moisture content of the soil layer created by the shade effect of the woody branches (Meyer 2020).<br>• As the woody branches decompose over time, it can increase the nutrient and carbon content of the degraded soils (NWU, n.d.). | • This method has to be maintained over the long-term to have a sustainable impact on soil. |

| | |
|---|---|
| Effectiveness | **Brush Packing:** Experiments from North-West University show that brush packing has a significant and positive impact on grass biomass. The impact on soil organic matter, soil moisture, pH and salinity appear mostly positive but is less clear (NWU 2020). |
| Timing | The best season for application of woody ash is autumn, but spring application could also be useful (Saunders 2014).<br>Brush packing should be done right before the rainy season. |
| Costs | Brush packing is considered highly cost-effective since it requires no inputs besides the branches from cleared bush. |

## Grazing Management

### Description

After bush control efforts, the treated area must rest to ensure the recovery of the herbaceous layer. A sustainable grazing or veld management programme should be developed to control re-growth (Dannhauser & Jordaan 2015).

### Options

1. **Kraaling** cattle overnight on the piece of land to ensure deposition of their dung and urine but grazing them elsewhere. This means less nutrients are deposed in the grazing areas, so there is a trade-off between bush-controlled land and current grazing sites (Zimmermann et al. 2017).
2. **Rotational Grazing:** Moving cattle to different portions of the pasture (paddocks) while the other portions rest. The intent is to allow the plants and soil time to recover (Undersander et al. 2002).
3. **Supplements:** Livestock can be supplemented with biochar and mineral rich ocean products – such as kelp- which are excreted and transferred into the soil by dung beetles (Zimmermann et al. 2017). There are also supplements to encourage livestock to browse more (SoK Workshop).

### Context Used

Sustainable grazing management measures should be widely adopted in bush encroached areas to limit risks of overgrazing and land degradation. Specific measures following bush control interventions should be implemented based on grass recovery. Rotational grazing for instance can only be implemented after grasses have started to regrow and would work best in combination with other post-harvesting measures.

**Synergies**

Rotational grazing allows for the implementation of other restorative measures on un-used plots such as re-seeding and soil enhancement with wood ash and wood acid.

**Preconditions**

Grass layers needs to already be growing on the site and land must be at some stage of recovery. Sustainable grazing management measures alone in heavily degraded areas might not be sufficient and have to be combined with other restorative measures.

**Advantages**

**Rotational grazing**

- More stable production during droughts (Undersander et al 2002)
- Greater cattle yield potential (ibid.).
- Maintain higher quality grass, decrease weed and erosion problems (ibid.).
- Promotes uniform soil fertility levels.

**Kraals**

- Short duration overnight kraaling has a positive effect on grass quality and biomass.
- Potential to limit wildlife conflict

**Disadvantages**

**Rotational Grazing:** Need to move feeding and watering stations often, which can be considered time consuming (Undersander et al 2002).

**Supplements:**

- Some supplements are not appreciated by cattle and can reduce their feed intake (Penn State 2019)
- Agro by-products and conventional supplements can be costly and not readily available in Southern Africa (Mudzengi et al 2020)

**Effectiveness**

**Rotational Grazing** to improve veld condition and better fodder capacity has shown better or equivalent results to chemical control, stem burning and cutting of bush, but has a much lower impact than re-vegetation (Harmse and Kellner, 2012).

**Supplements** through a mineral mix has shown positive results in shrub encroached sub-alpine landscapes used by cattle and thus associated with trampling, grazing and faecal deposition. The cover of shrubs and oligotrophic herbaceous species was reduced, and the average nutrient N value and forage pastoral value of the new vegetation types increased two years after the use by cattle (Probo et al. 2013). Further research is required.

**Kraaling**

Short-duration overnight cattle kraaling has shown effective results in improving grass quality and biomass in a Zimbabwean study site (Sibanda et al. 2016).

**Timing**

**Rotational Grazing:** The timing of rotations should be adjusted to growth stage of grass (Undersander et al. 2002)

**Costs**

**Rotational Grazing:** The only capital cost specific to this method is the costs for new fencing for each paddock and other movable infrastructure.

**Supplements**: Could be costly depending on the type and availability of supplements used.

Mortality of encroachers seems to be the highest when there is a combination of disturbances, which can greatly reduce their abundance (Hare et al. 2020). Due to the relatively low costs, fire is often recommended as the first measure if sufficient fuel load is available and should be followed up by goats. Biological control agents should always be last in line to maintain long-term effects (Lesoli et al. 2013). Based on the results of their study on the control of *Acacia mellifera* and *Acacia reficiens*, Hare et al. suggest that a combination of mechanical control with fire and browsers is the most effective way to maintain a balance between woody plants and grass in savanna ecosystems (Hare et al. 2020).

Fire and browsing can limit woody plant saplings from maturing to their resilient stage, where they are hard to kill. Encroached areas have high biomass that can provide fuel for hot fires capable of killing saplings. Fire is considered the main limiting factor to woody encroachment in semiarid savannas (Archer et al. 2017). Herbivores are attracted to recently burned sites, which relieves grazing pressure in other areas and supports the accumulation of fuel for prescribed fires. The result is a mosaic of vegetation with a variety of habitats (Archer et al. 2017).

## 3.2. Objective 2: Regrowth of Desirable Parts for Commercial Use

In very densely encroached areas, the risk to grassland ecosystems and species endemic to them must be assessed and managed acknowledging that savannas and grasslands are vital for global water, nitrogen and carbon cycles. Generally, where woody encroachment is at advanced stages, grassland restoration may not be feasible and other alternative uses should be assessed (Archer et al. 2017).

### Pruning

**Description**

Pruning removes the branches of bushes or trees instead of harvesting the entire plant. It encourages the bush to grow outwards and prevents heavy resprouting. Only the useful branches of trees and bushes are removed, and smaller branches are left for future harvesting (Baldiga et al. 2008). The main tools are shears for smaller branches or saws for larger branches (Hodel & Pittenger 2002).

There is no literature and no studies on pruning in Namibia. However, internationally, detailed instructions on how to prune woody plants are available (for example Hodel & Pittenger 2002). These should be trialled and tested in the Namibian context.

### Options

Based on international literature there are two main types of pruning cuts: (1) Heading back or (2) thinning out. Plants respond differently to the two different cuts (Hodel & Pittenger 2002).

1. **Heading Back** creates a flush of upright growth from the cut. The growth is often dense and vigorous. Especially for older trees, these shoots tend to be loosely attached and split out quickly (Hodel & Pittenger 2002).
2. **Thinning Out** is the removal of lateral branches at their base. Through thinning, the plant retains its original growth and becomes more open. Because more light can penetrate the canopy, the foliage grows deeper into the tree (Hodel & Pittenger 2002).

Pruning is different for young and old trees:

- **Young Trees:** Pruning is used to direct the growth, so they perform as desired once they mature. Plants with strong central leading branches require limited pruning, while trees with a more irregular growth require more pruning. Trees with abundant lateral growth should be thinned out. By the third season, thinning out should be reduced to allow for later selection of the best branches. If a woody plant does not develop enough laterals that can be used, the head of the tip of the leading branch can be pinched off to encourage the growth of a second leader while pinching the tips of other shoots (Hodel & Pittenger 2002).
- **Mature Trees:** Older trees should have reached their main structure and require limited pruning except for size control. The top of the tree can be opened up to let more light in to ensure branches on the inside remain healthy. Thinning can reduce spread and size of the tree (Hodel & Pittenger 2002).
- **Broadleaf Shrubs:** Hodel & Pittenger recommend cutting the older and larger stems and leaving the younger stems. For very large overgrown shrubs, it may be necessary to clear out all the older stems near the ground for two to three years. They can then be thinned out and headed until they reach desired shapes (Hodel & Pittenger 2002).

### Context Used

Pruning can be used if woody plants should have a certain shape or appearance (Hodel & Pittenger 2002). It may thus be useful to manipulate the woody plants through pruning to produce branches of the right size and shape for different value chains.

### Synergies

This should go hand in hand with soil enhancement measures to ensure the sustainability of the resource base and other potential measures to ensure densities are appropriate for the production of good quality woody biomass and easy access to the resources for harvesting.

### Preconditions

Pruning to direct the growth of the plant should be done during their active growing season or phase of most rapid growth to ensure that the growth rate is maintained (Hodel & Pittenger 2002) for recurring harvesting.

| Advantages | | Disadvantages | |
|---|---|---|---|
| | • Pruning can help to shape young plants into desired forms (Hodel & Pittenger 2002) to ensure it can be used.<br>• Pruning and thinning can | | • Done incorrectly pruning can do considerable damage to the shape and structure of the plant (Hodel & Pittenger 2002)<br>• Pruning trees when they |

| | | | |
|---|---|---|---|
| | ensure that patches of woody plants are maintained contributing to habitat heterogeneity and species diversity (Joubert & Zimmermann 2002). | | become larger can be harder and less effective due to scarring and excessive regrowth (Hodel & Pittenger 2002). |
| Effectiveness | Pruning is considered the most effective way to ensure woody plants or shrubs grow a specific way (Hodel & Pittenger 2002). | | |
| Timing | Light pruning to remove unwanted shoots and removing damaged or weak branches can be done anytime. To maintain growth, pruning should be done in spring, which is often the season of most rapid plant growth. Shaping young trees is also best done in the growing season. To slow plant growth, plants should be pruned towards the end of their growing for the season (Hodel & Pittenger 2002). | | |
| Costs | The equipment for pruning is relatively inexpensive. However, it is a very labour-intensive operation. | | |

The two objectives presented above are not mutually exclusive. Restorative measures must be implemented in agro-forestry / bush farming models to ensure resources are maintained in the long term. Thus, measures presented above (especially measures presented under "Measures to Enhance Biodiversity and Soils") are critical.

## 3.3. Factors that Influence Post-Harvest Treatment Success

The most suitable post-harvest treatment often depends on the initial bush control measure and there are synergies between different methods. For example, fire is often recommended as the first measure if sufficient fuel load is available and should be followed up by goats (Lesoli et al. 2013).

On thinned land, a balance between browsers, grazers and mixed feeders of different game species must be found. Wildlife tends to concentrate in recently thinned areas. Thus, the treated area should be large enough to reduce the pressure on the grasses (Smit n.d.). If livestock is held in paddocks, they should only be allowed to graze on thinned areas in the dormant season of the herbaceous layer to allow grasses to recover and produce seeds (Smit n.d.).

The timing of different measures is vital to ensure their success. Studies indicate that regrowth is the lowest and mortality the highest when they are removed during the wet season, which facilitates subsequent post-harvest treatments (Smit 2004).

The natural functioning of the ecosystem can be used to promote the creation of an open savanna landscape (Smit n.d.). It is based on the distance between trees. The larger the tree, the wider the tree spacing, especially for *Acacia* species. If a large tree is killed, the remaining individuals grow quicker due to the reduced competition. If trees are thinned very selectively, the remaining trees will grow and suppress other woody plants in the area (Smit 2004).

# 4. Overview and Way Forward

## 4.1. Summary Matrix of Measures

| Measure | Conditions / Context | Timing | Costs | Effectiveness | Risks |
|---|---|---|---|---|---|
| **Fire** | Fuel load between 2000 and 3000 kg/ha is available. | Before the growing season. Every 20 years can be sufficient. | Cheapest *(to be quantified in CBA)* | Can kill 98 – 99% of Acacia species with the right regime. | Knowledge require to avoid damage to basal layer, ensure sufficient rest and minimise nutrient losses.<br>Insufficient fuel load in arid or severely degraded environments. |
| **Biological Control** | Low canopy heights (max. 2m) with species eaten by browsers. | Anytime if sufficient forage is available. | Inexpensive if biocontrol agents are available on farm / in country *(different options to be quantified in CBA)* | In combination with fire, a reduction of bush density by 60% within 40 years can be achieved and coppicing is reduced to 28%. | High level of management and infrastructure required (goats).<br>Invertebrate biocontrol agents may not be readily available and there is a lack of research on this in Namibia. |
| **Mechanical Control** | Accessible land and available machinery / sufficient workers. | Anytime, best towards the end of the growing season. | Expensive due to labour and machinery required.<br>Rolling: N$ 308/ha<br>Manual: N$150/ha | Considerable coppicing. Not viable as stand-alone measure. Effective with fire and browsing. | If heavy machinery is used, heavy impact on the soil and desirable vegetation (herbaceous layer). |
| **Chemical Control** | Soil Applied: Adequate distance between target and non-target, clay content below 30%.<br>Plant Applied: Smaller than 2m.<br>Distance to waterbodies. | Before the wet season / active growth phase. | Most Expensive<br>Manual Foliar Application: N$170 - N$200/ha to N$ 600 and N$1200 per hectare.<br>Stem treatment is cheaper. | Effective when applied in growing season. | Impact on environment and human health. |
| **Grass Reseeding or Inter-Seeding** | Thinned areas with relatively fertile soils and some woody plants providing shade and nutrients. | Wet season | Very Low<br>If seeds can be collected on farm. | Depends on water availability. | Lack of water.<br>Introduction of invasives due to lack of governance. |

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|---|---|---|---|---|---|
| **Soil Enhancement** | Areas where bush has been removed -especially with chemical and mechanical control. | Spring / before rainy season. | Inexpensive / Potentially Labour Intensive | Brush Packing has a positive effect on grass biomass. | Requires considerable commitment and follow-ups. |
| **Grazing Management** | All areas that are under agricultural production. | All Year | Medium depending on existing infrastructure.<br>Medium – High: Supplements *(different options to be quantified in CBA)* | Can have equivalent or better results than chemical, mechanical control and stem burning. | Implementation of rotational grazing can be considered too labour intensive.<br>Supplements may not be readily available or expensive. |
| **Pruning** | To achieve a specific shape or size of branches for commercial purposes. | Spring to maintain growth. | Inexpensive equipment but labour intensive. | Most effective way to direct plant growth. | Requires knowledge to avoid damage and excessive resprouting. |

## 4.2. Knowledge Gaps & Data Collection

| Gaps identified | Contact / Source / Location of field trials for data collection<br><br>*To be further defined with reference group feedback* |
|---|---|
| Pruning of trees for specific value chains | Contact Namibia Charcoal Association to identify and contact farmers who practice this measure |
| Synergies/compatibility between different aftercare measures | Trials realised in Outjo by researchers and Farmers (Farm Sofienhof, Jerome Boys) |
| Soil enhancement used after bush control in Namibia: current practices and opportunities (including brush packing) | Targeted N-BiG and Farmers Unions members |
| Factors affecting re-seeding success, general data on re-seeding interventions in Namibia | Targeted Farmers Unions members |
| Impact of bush thinning intensity on each measure's success rate | Targeted N-BiG and Farmers Unions members |
| Role of remaining large trees on aftercare measures success and limitation of woody vegetation regrowth | |
| Opportunities and indirect cost of fire to limit regrowth: main risks, resting time required for land to become sustainably productive | Fire management experts, targeted Farmers Union members |
| Recent developments in herbicides (arboricides) registered for use in Namibia | |
| Environmental and financial impact of rolling as mechanical aftercare method | Targeted N-BiG members |
| Direct, indirect and opportunity costs of the different aftercare measures | Financial data from farmers and market prices for direct costs.<br>Indirect and opportunity cost: varying on the assumptions primary data from consultation with farmers and experts or secondary data |

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