BMCC II Aftercare

ENVIRONMENTAL ASSESSMENT

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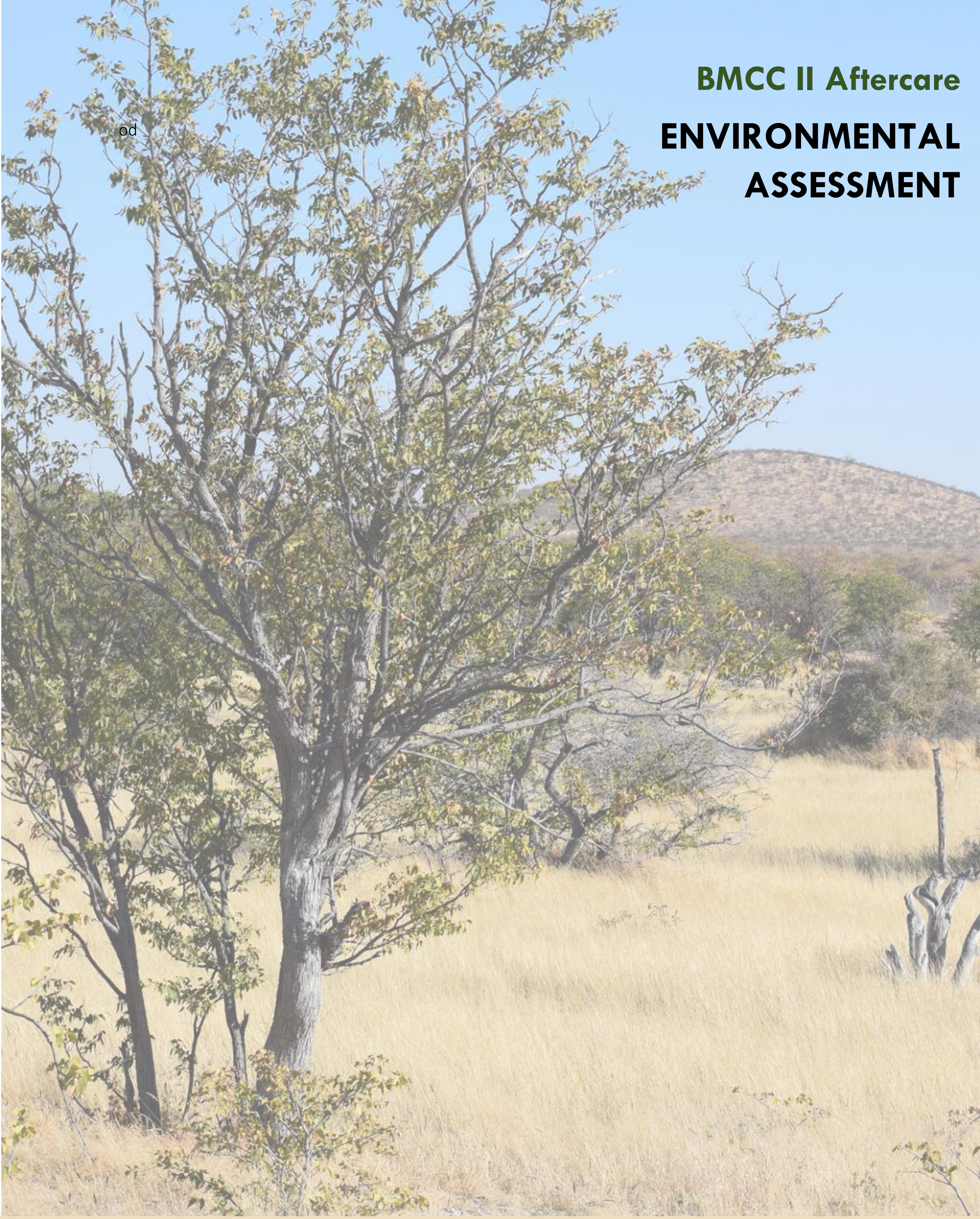

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List of Abbreviations

CO_2	Carbon Dioxide
ha	Hectares
LU	Land Units
MEFT	Ministry of Environment, Forestry and Tourism
Pers. Comm.	Personal Communication
pH	Potential of Hydrogen
TE	Tree Equivalents
UNEP	United Nations Environment Programme
yr	Year

1. Background

1.1. Bush Thickening

Bush thickening is the process of increasing density and cover of the woody layer in savannas to such an extent that grass production is negatively affected through the resulting increase in competition (Joubert 2014). It can cause changes in the natural vegetation composition and herbaceous cover (Lesoli et al. 2013). Encroaching woody species compromise ecosystem stability, impair the productivity of rangelands and erode natural capital (Lesoli et al. 2013).

Key causes for bush thickening include:

- Poor grazing management
- The replacement of adapted indigenous animals, particularly browsers, with less adapted high producing grazing livestock at sometimes high stocking rates
- Changes in the climate
- Differences in topography and soils and changes in these factors
- Increases in atmospheric CO_2
- Changes in natural fire regimes
- The erection of fences that restricts the natural movement patterns of the herbivores

The extent of bush thickening in Namibia is estimated to be between 45 million hectares (Seebauer et al. 2019) and 62 million hectares (Rothauge 2014). Due to the extent of bush thickening in Namibia, 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 on 18 880km^2 (1.9 million hectares) by 2040 (Hengari 2018).

1.2. Positive and Negative Impacts of Bush Thickening

Positive Impacts	Negative Impacts
Habitats: Bush creates 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 (Smit 2005). **Soil Fertility:** Trees can have a positive impact by enriching the soil under their canopy through the decomposition of organic matter (Smit 2005). The nutrients available to plants are higher in encroached landscapes due to the nitrogen fixing ability of plants in the Fabaceae family. Bush with their deep roots can access nutrients from deeper levels and therefore acts as a nutrient recycler (Seebauer et al. 2019). **Soil Hydraulic Properties:** Infiltration of rainwater is highest close to the canopies of woody plants, due to the plant litter underneath the canopy. The extensive distribution of roots creates macropores, which have a positive effect on infiltration (Eldridge et al. 2015). **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	**Hydrology:** Woody encroachment can reduce underground water levels and have a higher air turbulence and lower albedo increasing their potential evapotranspiration. They also have a higher canopy interception of rain (Archer et al. 2017). **Biodiversity:** Woody encroachment can shift landscapes from grassland to shrub or tree savannas and open savannas to closed woodlands or shrublands. As a result, grassland ecosystems and species are endangered in many parts of the world (Archer et al. 2017). **Soils:** Woody encroachment and the resulting increases in biomass can change soil microbial communities and slow decomposition rates and thus soil fertility. Bare areas between bushes in encroached landscapes can lead to soil erosion (Seebauer et al. 2019). **Economic & Social:** The grazing capacity in many Southern African countries has considerably declined making livestock production economically unviable in many areas (Smit 2004). Besides, bush encroached landscapes are often less aesthetically pleasing and have a reduced aesthetic value for tourism (Lesoli et al. 2013).

likely to become net sinks (Archer et al. 2017).

Economic Opportunities: Bush thickening can promote land-uses using the woody biomass for commercial purposes to diversify the economy and generate income (Archer et al. 2017).

1.3. Bush Control and the Need for Post-Harvest Treatment

A key response of land users to woody encroachment is the removal or thinning of woody plants to restore the savanna ecosystem (Smit 2004). However, many woody encroachers do not die after stems and the canopy are removed and strongly regrow from the roots and/or stumps (Strohbach 1998). Positive effects of bush control were mostly short-lived and only persisted for 5 to 7 years (Archer et al. 2017). The decline of grasses sometime after the harvesting or control of bush is driven by the re-establishment of bush and increased availability of resources such as water, light and 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 also stimulate seedling establishment and sapling growth (Archer & Predick 2014).

Where the land-use objective is the restoration of rangelands, post-harvest treatment of woody plants after bush control is vital to maintain the productivity of the herbaceous layer (Archer & Predick 2014, majority of interviewed experts). A single bush control operation is unlikely to maintain the restored state indefinitely, therefore requires continuous planning and implementation to ensure the stability of the restored ecosystem (Pers. Comm. Leon Lubbe). 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). 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 (Lesoli et al. 2013).

Definition

For this assessment, post-harvest treatment measures include all measures to contain the regrowth of bush after initial bush control -independent of whether the bush is harvested for commercial use or to restore the land.

Once the average tree density exceeds **75% of the maximum potential Tree Equivalent (TE)/ha**, the land is considered re-encroached and in need of another bush control operation.

1.4. Post-Harvest Treatment Measures

Fire

Fire plays an important ecological role in the maintenance of stable and productive savanna communities. However, attitudes towards the use of fire for the management of landscapes are often negative and it is seen as a last resort despite being a natural way to control bush thickening (Booysen & Tainton 1984). Naturally occurring fires created a mosaic of burned and unburnt areas maintaining the diversity of the vegetation and habitats for wildlife (Booysen & Tainton 1984). The exclusion of fire or infrequent burning can lead to bush thickening, reducing the herbaceous layer and causing some wildlife species to migrate to more open habitats (Booysen & Tainton 1984, Kennedy & Potgieter 2003).

Both crown and surface fires occur in African savannas, although surface fires are more common. Crown fires only develop under dry conditions with low fuel moisture, strong winds, high temperatures and low humidity. Fire often tends to avoid areas with denser bush due to the lack of grass fuel or predominance of non-flammable species. Once bush densities become very high, the effectiveness of fire as a management tool becomes less effective than in the initial or re-sprouting stages (Booysen & Tainton 1984). However, fire can be effectively used to reduce re-sprouting as it is effective in killing seedlings and juvenile trees (Hannan et al. 2008, Holdo 2005, O'Reilly et al. 2006, Zimmermann & Mwazi 2002, Joubert 2014).

The fire intensity is influenced by the moisture level of the fuel and the season of burning. Fire intensity is the highest toward the end of the dry season before the spring rains (normally in October and November) because the moisture content is low. It is also influenced by atmospheric conditions, mainly humidity (Booysen & Tainton 1984, Kennedy & Potgieter 2003). Burning at the end of the dry season to control thick bush is best for the following reasons:

- The temperature of the plant tissue of bush and trees is already high,
- Trees and bushes already produced new leaves and plant reserves are likely depleted,
- The moisture content in the bark is likely to increase to resume active growth, this favours thermal conductivity,
- New leaves are vulnerable to fire forcing the plant to use depleted plant reserves to create new leaves (Booysen & Tainton 1984).

The frequency of burning should be determined by the available fuel load, which is strongly affected by rainfall and the rate of grazing. Naturally, the frequency of fires in arid environments (3 to 5 years – longer during dry periods) is lower than in moist environments (1 to 2 years) (Booysen & Tainton 1984, Kennedy & Potgieter 2003). The current use of fire is largely determined by land-use and legislation (Booysen & Tainton 1984). The use of fire in Namibian legislation is guided by the Forest Act 12 of 2001 (currently under revision). The Ministry of Environment, Forestry and Tourism (MEFT) also provides guidelines for the use of fire in their Fire Management Strategy for Protected Areas.

Biological Control

Biological control measures use living organisms to reduce the reproductive capacity, growth and effects of woody plants (Lesoli et al. 2013). It is considered an environmentally friendly and progressive type of pest control. Once introduced some biocontrol agents (e.g. fungi, insects and wildlife) spread and persist in the landscape for a long time with little additional costs involved (Randall & Tu 2001).

There are three general approaches to biological pest control according to Randall and Tu (2001):

1. **Classical Biocontrol:** Non-native pests are controlled with biocontrol agents from the natural range of the pest.
2. **New Association or Neoclassical Biocontrol:** Native pests are controlled with non-native biocontrol agents.
3. **Conservation, Augmentation and Inundation Biocontrol:** Aim to increase the abundance of biocontrol agents that are already in the landscape by modifying the environment. These are often focused on maximising native biological diversity.

Goats

Goats are commonly used to manage bush thickening worldwide. Goats are opportunistic mixed feeders but prefer browsing. They can stand on their back legs to reach forage at greater heights, climb rocks and branches, and strip bark damaging trees. Intermediate feeders range over large areas and can adapt their foraging behaviour to seasonality in food availability and are thus more versatile (Elias & Tischew 2016, Lipson et al. 2011). They can survive on degraded land (Rothauge et al. 2003), without water for some time (Lipson et al. 2011) and can sustain themselves during droughts (Rothauge et al. 2003).

Goats alone may not be able to control regrowth but can be successful in combination with other methods. Browsing by goats was neither affected by physical characteristics (e.g. thorn size) nor differences in chemical composition of woody encroachers, who often consist of a variety of chemicals (e.g. lignin and tannins) (Stolter et al. 2018, Raats 1998, Elias & Tischew 2016). Their narrow muzzles with mobile lips and tongue allow them to select desirable parts of the plant and avoid thorns (Elias & Tischew 2016). In a Namibian study, Boer goats mainly consumed woody plants (51,24%), while perennial grasses (18,77%), forbs (18,71%) and annual grasses (10,66%) made up the balance. They used more feed from woody plants, which is less diverse, than abundant herbaceous grasses (Rothauge et al. 2003).

In a Namibian study, goats preferred sicklebush over other encroacher bushes and ate about 90% of the biomass (Stolter et al. 2018). The impact on the vegetation composition often depends on the goat breed. In Germany, goats did not completely bite off the grass in spring and autumn even at high stocking densities of 0,6 – 0,8 LU/ha/yr. In spring, goats heavily browsed wood plants and spent less time grazing (Elias & Tischew 2016). Although these findings suggest that goats mainly browse, do not directly compete for grazing and can help to control bush thickening after initial thinning efforts, many farmers are reluctant to stock goats (Pers. Comm. Bertus Kruger and Wolfie von Wiellich). The reluctance can be explained by the risk posed by predators and the intense management required (Rothauge et al. 2003). Boer Goats can successfully control woody thickening, if the intensity and frequency of their browsing can be managed (Van Oudtshoorn 2015). However, considerable management is required, and they are predator prone (Pers. Comm. Peter Cunningham).

Wild Grazers & Browsers

Grazers and browsers can have a considerable effect on the vegetation and conditions of rangeland. They also provide opportunities for hunting, tourism and meat production (Booysen & Tainton 1984).

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 megaherbivores such as elephants (Smit n.d.), who can create damage and change height strata to make other measures (e.g. insects, fungi or fire) more effective (Pers. Comm. Peter Cunningham). However, wild browsers, hares 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, enhance biodiversity and create economic opportunities around consumptive and non-consumptive utilisation of game (Archer et al. 2017).

Insects

Since the 1970s, considerable research on biological control using insects for invasive Australian *Acacias* has been conducted in South Africa (Zachariades et al. 2017). Insects can be used for different purposes. In the case of Australian *Acacia* species in South Africa, nine different insect species were used to reduce the reproductive capacities of the valuable invasive *Acacias* allowing the plants to grow and using them commercially. In the short-term, this does not reduce the density of the invader, but the seed-reducing benefits created by specific insect species can considerably reduce the speed of densification and spread. The impact of insects increases under stressful conditions (Impson et al. 2011, Zachariades et al. 2017). In some *Acacia* species, insects were able to cause shoot die-back, stunting, reduced seed capacity and mortality in stressed trees (Impson et al. 2011, Lesoli et al. 2013). Especially seed-reducing insects can make mechanical control or chemical control viable because the rate of re-establishment is reduced considerably (Zachariades et al. 2017).

The Australian *Acacias* targeted in the South African studies have similar characteristics as native encroachers in Namibia: They perform well on nutrient-poor land, grow quickly and reach maturity fast, and produce large quantities of seeds. They are often adapted to fire and seed germination may be stimulated by fire (Impson et al. 2011).

Both insects and fungi as bio-control agents normally require a high initial investment to find suitable species. However, once control species have been found they are relatively cheap to apply and sustain themselves in the field (Zachariades et al. 2017, Randall & Tu 2001). Biological control programmes should be extensively researched and tested to ensure their suitability and minimise risk for other organisms in the ecosystem (Zachariades et al. 2017, Randall & Tu 2001). For alien invasive plants, both insects and fungi can be among the most effective and powerful tools to control thickening, because they can act over huge areas in the long-term, which makes it especially relevant for natural areas (Randall & Tu 2001). Their potential use for the control of native encroachers must be extensively researched in a Namibian context.

Fungi

In the 1970s, a disease affecting blackthorn (*Senegalia mellifera*) was identified in the northern regions of Namibia. This disease became an epidemic in the mid-1980s affecting up to 10 million hectares of the country and causing dieback. The illness of blackthorn was caused by four fungi (Van der Merwe 2007):

- *Phoma glomerata*
- *Phoma eupyrena*
- *Phoma cava*
- *Cytosperma chrysosperma*

Indicators of the disease are 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 disease is slow-acting, and plants can recover if the stressor is removed. Phase I (Yellowing & Defoliation) takes a few seasons. 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).

Blackthorns of all size classes, ages, geographical locations, habitats, climatic zones, soils as well as isolated trees and thickets were infected by fungi. Cankers in the stem, twigs and shoots influenced the mortality rate. No coppicing was observed during the Namibian study. The fungi can be latent in the plant tissue for a long time before the ecological and physiological conditions are favourable and the disease breaks out and the first symptoms show. *P. glomerata* produces multiple phytotoxic compounds, which can create pathways for the other fungi species (Van der Merwe 2007).

Fungi have not been used in a targeted manner in Namibia to control the thickening of bush. However, in South Africa, fungal pathogens were used successfully to control alien invasive Australian *Acacias*. These fungi were highly host-specific and created considerable damage to host plants under the right environmental conditions (Zachariades et al. 2017). The rust fungus (*Uromycladium tepperianum*) reduced tree densities by 70 to 90% between recurring fires (Zachariades et al. 2017). These reductions often happen over several years or decades.

Considerable research is required to find appropriate fungi for Namibian encroacher species and determine their effectiveness and potential negative impacts -including the potential for host shifts. This also involves research on how to best "apply" the fungi to the land or species to be controlled.

Mechanical Control

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).

In larger areas, heavy machinery such as bulldozers which uproot the entire plant is used. The high cost of heavy machinery probably prohibits its use as a post-harvest measure. One exception is heavy rollers, which tend to be more cost-effective (Pers. Comm. Koos Briedenhann).

Manual Control

Manual methods -such as pulling and cutting- 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 (Van Oudtshoorn 2015).

Chemical Control

Various chemical herbicides developed to kill shrubs and trees (arboricides; FSC's pesticides) are registered in Namibia to control bush species. Arboricides, however, differ with regards to the mode of application, the safety of use and potential negative environmental impacts. Arboricides stay in the soil for several years (Lesoli et al. 2013). In Namibia, the following active ingredients are registered for bush control (based on Baldiga et al. 2008 & Honsbein et al. 2012):

Active Ingredient	Chemicals	Environmental Concerns
Bromacil	Bromacil G10: Granule Bromotil: Suspension Concentrate Foliar: Manual Buschwacker: Granule, Soil Applied / Aerial, Suspension Concentrate, Foliar: Aerial / Manual Spray Bromoxynyl: Suspension Concentrate, Foliar: Manual Brushfree: Suspension Concentrate, Foliar: Manual Hyvar X: Wettable Powder Hyvar XG10: Granule	Not easily absorbed by soils -especially with low organic matter content- if applied at larger rates and can leach into groundwater. Should not be used in areas with drinking water reservoirs or in recharge areas. It is more persistent in soils with high organic matter content and can retain residues to up to 2 years. Has a lengthy soil half-life, especially in dry conditions (2-8 months and up to a year). **Not approved in EU except for essential use*** (EU Pesticide Database).
Bromacil / Tebuthiuron Mix	Bundu: Suspension Concentrate, Foliar: Manual Savana 500 SC: Suspension Concentrate, Foliar: Manual	↕
Tebuthiuron	Molopo (old Graslan 20P/ Grazer	Transport off-site through volatilisation into the

	GG): Macro Granule, Soil Applied: Manual / Aerial Molopo SC (old Reclaim/ Grazer SC): Suspension Concentrate, Foliar: Manual	atmosphere, in surface runoff and in water moving through the soil. Becomes more toxic in soils with high clay content and organic matter content: most effective in soils with low clay content. Resistant to biological and chemical degradation and the principle route of dissipation is mobility. **Not approved in the EU** (EU Pesticides Database).
Picloram (as potassium salt)	Access Suspension Concentrate, Foliar: Aerial / Manual Browser: Suspension Concentrate, Foliar: Aerial / Manual	Leached easily through the soil. Substantial effects on soil microbial populations and community structure -especially in soils with low organic matter and fertility. **Approved in the EU** (EU Pesticide Database). **On the FSC list of highly hazardous pesticides** within the "Restricted" active ingredients due to acute toxicity OR chronic toxicity OR environmental toxicity (FSC 2019). On the **List of Restricted Pesticides by the US Environmental Protection Agency** (EPA n.d.)
Picloram - Triclopyr Mix	Tordon Super: Oil Miscible Liquid	
Picloram - 2,4-5 T (Trichlorophenoxyacetic acid) Mix	Tordon 22K: Liquid	
Triclopyr (butoxyl ethyl ester)	Garlon 4: Emulsified Concentrate	**Approved in the EU** (EU Pesticide Database).
Ethidimuron	Ustilan 10 GR: Granules Ustilan 20 GG: Macro-Granules Ustilan 70 WP: Wettable Powder	**Not approved in the EU** (EU Pesticides Database).

** The European Commission evaluates every active substance for safety based on the impacts on people's health, (e.g. residues in food), on animal health and the environment before the product reaches the market.*

*** The FSC supports Namibian regulations. The use of chemicals is discouraged, and a good justification must be provided for their use. Chemicals prohibited on the FSC List of Highly Hazardous Pesticides should not be used. Certified Organisations should use integrated management systems to avoid, or potentially eliminate, the use of chemical pesticides. If pesticides are used, potential damage to the environment and human health should be prevented, mitigated, and/or repaired (FSC 2019).*

*Meats free from any [animal] growth promoter as defined and listed as a prohibited or controlled substance in the **Prevention of Undesirable Residue in Meat Act (Act 21 of 1991)** and its Regulations, notices and amendments. The act does not refer to residues originating from arboricides. Currently, meat exports are not affected by local use of EU banned or restricted arboricides, as long as it is legally used according to Namibian Acts and regulations. Standards and rules of the FAN Meat Scheme are based on good practice, Namibian legislation and recommendations by the World Organisation for Animal Health (OIE). FAN Meat certification is internationally acknowledged and ISO 9001 certified (Meat Board 2019, Republic of Namibia 1994, Government of South West Africa 1947).*

Soil Applied Arboricides

The chemical is applied to the soil surface within the root range of target plants. These arboricides dissolve in rainwater and are transported to the roots of plants as it infiltrates the soil. The active ingredient is absorbed by the roots and translocated to the leaves through transpiration where it inhibits photosynthesis. Woody plant species may successively loose and regain leaves until death occurs (Bezuidenhout et al. 2014). Commonly used soil-applied arboricides are non-selective. The use of soil applied arboricides is generally not recommended in post-harvest programmes due to this non-selective nature (arboricides may affect proximate desirable plants) and the risk of leaching from the target area (SAIEA 2016). The long-term residual effects of soil-applied arboricides have not been well studied in a Namibian context (SAIEA 2016, Pers. Comm. Ben Strohbach & Axel Rothauge).

Stem Applied Arboricides

Are applied to the freshly cut / sheared surface of harvested plants as soon as possible after harvesting (i.e. within an hour) (Smit et al. 2015, Van Oudtshoorn 2015). Failure of applying the arboricide according to the specified time can result in poor control of woody plants. Stem applications are selective and only the treated plants are controlled. A disadvantage of stem applications is that a percentage of harvested plants would probably die naturally after being harvested and some arboricide will be unintentionally "wasted". Cunningham and Detering (2017) in a Namibian study showed that on average about half of *Senegalia mellifera*, *Vachellia reficiens* and *Terminalia pruniodes* did not coppice after being cut close to the ground (stem diameter 75-118 mm). *Dichrostachys cinerea*, however, coppiced prodigiously, especially on soils with a high clay content (Cunningham & Detering 2017). This should be substantiated by further research.

Foliar Treatment

The foliage of target plants can be sprayed with an arboricide. Foliar control is effective where stem treatment is not feasible, e.g. where stems are broken of (i.e. rolling operations) rather than cut or sheared or where coppicing already occurred. To effectively control coppicing plants, regrowth after harvesting should be allowed (e.g. 2-10 months; growth knee to hip height) and the foliage should be green and fully expanded to ensure good arboricide action (always follow label instructions). Foliar applied arboricides are selective and saplings and seedlings can be effectively controlled (Smit et al. 2015). Unselective spraying - for example with tractor boom sprayers- will negate the selectivity and a substantial amount of arboricide may reach the soil surface. It should therefore be discouraged. Foliar control is susceptible to drift in windy conditions, potentially harming desirable plants. Spraying during suitable weather conditions is essential.

The FSC's list of hazardous pesticides, EU Pesticide Database and other regulations of export markets should be frequently consulted as these resources are continuously updated as new information becomes available. New developments are also underway and new arboricides may replace or complement the existing registered chemicals in the future.

Grass Reseeding or Inter-Seeding

Woods et al. (2012) suggest that effective control must include both top-down and bottom-up control to ensure the removal of bush to a specific density and minimise the chances of re-growth and further densification. 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).

The seeds can be dispersed by livestock -by mixing the seeds into their feed-, which is the most cost-effective, or by creating seedcakes, seed bombs or blocks by mixing the seeds with manure, biochar and other growth enhancers. They can also be dispersed by drones (Pers. Comm. Ibo Zimmermann).

Soil Enhancement

The removal of biomass can have a negative impact on the soil -the severity depending on the initial bush control method used. To speed up the restoration of soil fertility, minerals removed through the harvesting of bush must be returned (Zimmermann et al. 2017). All soil enhancement measures considered here are by-products of the initial bush control or bush harvesting operations. Other measures -such as organic or chemical fertilisers- will not be further discussed here.

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).

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).

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.).

Charcoal / Biochar is very porous and thus easily retains moisture. It can improve the soil by increasing water retention and water permeability. The application of biochar can positively influence the physical, chemical and biological properties of soils, thereby boosting plant productivity (Zimmerman et al. 2020). 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.).

Grazing Management

Grazing management after bush harvesting or control can directly influence the rate of woody regrowth and indirectly the competitiveness of the herbaceous layer. After bush control efforts, the treated area must rest from grazing 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). **Kraaling** cattle overnight on the piece of land to ensure deposition of their dung and urine, locally enhancing the competitiveness of grasses, and physical damage to woody plants. They should be grazed elsewhere creating a trade-off between nutrient deposition on bush-controlled land and current grazing sites (Zimmermann et al. 2017). **Rotational Grazing** includes 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). 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). Supplementing animal feed can return minerals back to the land, lead to more nutritious grass, increase livestock performance and make other land uses -e.g. milk production- viable again. It is most cost-effective when livestock can choose by separately providing supplements instead of mixing it into all feed (Pers. Comm. Ibo Zimmermann).

Some grazing specialists suggest that grazing is an important ecological driver with short-duration and high-intensity grazing mimicking evolutionary herbivory -especially in grasslands (SANBI 2014). However, these views are widely discussed and questioned. Not all land can withstand the same grazing pressure and responses may differ (SANBI 2014). Australian guidelines on controlling bush thickening acknowledge that livestock can play a role in controlling bush thickening by stressing woody plants (e.g. by trampling) and thus preventing their dominance. However, it requires careful management to minimise damage to desirable grass species and avoid overgrazing which can support bush thickening (Commonwealth of Australia 2004). Different animals graze differently, thus creating different outcomes. Bulk grazers -such as cattle, white rhinos and buffalo- are less selective and mow through a landscape and thus have a lower impact than selective grazers. SANBI suggests that biodiversity-friendly stocking rates should be conservative (SANBI 2014).

Pruning

After the initial control of areas with thick bush, the regrowth of the bush often has a different structure and species composition than the original stands (Smit et al. 2015, Cunningham & Detering 2017, Pers. Comm. Jerome Boys). Harvested single stem trees coppice after harvesting and become multi-stemmed trees. These trees require pruning similar to plantation forestry (Cunningham & Detering 2017).

Pruning removes the branches of bushes or trees instead of harvesting the entire plant. It encourages the bush to grow outwards and prevents heavy re-sprouting. 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 completed 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. Pruning coppiced bush too soon (e.g. within a season) or too drastically after the initial harvest resulted in a high mortality rate of the pruned plants (Pers. Comm. Jerome Boys).

For a more detailed background and description of individual post-harvest treatment measures, please refer to the State of Knowledge Report produced under this consultancy.

2. Methods

2.1. Objectives & Scope

The main objective of the environmental assessment was:

"To analyse the impact of different post-harvest treatment measures on various components that constitute the environment and provide valuable ecosystem services."

The environmental assessment will allow a comparison between different measures as well as ranking measures based on their environmental risks. Socio-economic indicators will be discussed as part of the cost-benefit analysis conducted for the post-harvest measures.

2.2. Rationale

Different post-harvest treatment measures have different impacts on the environment and are closely tied to the initial mode of bush control, appropriate planning and handling, as well as the conditions and geophysical features of individual sites.

Some measures often promoted in the past can have a considerable detrimental impact on the environment and can impair the provision of vital ecosystem services in the long-term often exacerbating bush thickening instead of mitigating it. Experiences within Namibia and in other countries of the world have led to advances in the post-harvest treatment of bush, questioning the viability of established control measures under shifting political agendas emphasising climate change adaptation and mitigation, biodiversity conservation and land degradation neutrality. This justifies the critical assessment of the environmental impacts of different post-harvest treatment measures to support decision-making, keeping in mind that the strength of different measures often lies in their combination and Integrated Management Plans.

2.3. Data Collection & Analysis

The tight time frame of the project limited opportunities to collect data in the field. The information presented in this report is based on (1) a literature review looking at national and international literature and (2) semi-structured expert interviews.

The choice of indicators was based on the Global Environmental Outlook methodology – an integrated assessment of the state of the environment regularly conducted by the United Nations Environment Programme (UNEP). Indicators looked at in this assessment include:

- Air: Includes emissions as well as potential pollution and dust produced by the different measures.
- Water: Assesses impacts on different components of the hydrological cycle and the water holding capacity of the soil and landscape.
- Land: Looks at the primary productivity of the land, nutrient cycling, impacts on soil properties and conditions, erosion, surface temperature of the soil as well as the aesthetic appeal of the landscape.
- Biota: Considers impacts on the habitat, biological diversity and species composition of flora and fauna, alien invasive species as well as food and feed availability.

Semi-structured interviews were conducted with experts in the field to focus on specific measures based on their expertise. A question catalogue was developed to ensure consistent data collection and comparability of results.

2.4. Limitations and Research Needs

Information and data on the impacts of post-harvest measures on the environment are scant. It is therefore often necessary to deduce environmental impacts from studies done on the bush control or harvesting that precedes post-harvesting measures.

While woody encroachment is a global phenomenon and subject to considerable research, the post-harvest treatment of harvested or controlled rangelands is a more recent trend. In Namibia, the use of post-harvest treatments is rare (Honsbein 2012) and few practical examples exist. Thus, information is limited and detailed studies are unavailable. While this consultancy is a first step towards collecting and aggregating information on the post-harvest treatment of encroacher bushes, it is not conclusive and must be substantiated by research conducted in Namibia.

Some knowledge gaps that should be addressed in the future include:

1. Biological Control with Wild Browsers and Goats: Effectiveness for controlling different encroacher species as well as the duration and stocking rates required.
2. Fire: The opportunity cost of resting the land before and after a fire to ensure the accumulation of fuel and the recovery of the ecosystem post-burn.
3. Mechanical Control: Severity of soil compaction in Namibian context and related impacts.
4. Chemical Control: Stocktake of active ingredients registered in Namibia for bush control. Advances and new active ingredients. Local information about persistence and toxicity cases.
5. Insects & Fungi: Potential native species that can effectively control bush thickening and their potential effects on the environment.
6. Regrowth: The rate of regrowth of different encroacher species under different initial control and aftercare measures.
7. Pruning: Viability for different value chains in Namibia and best practices.

3. Environmental Impacts of Post-Harvest Treatment Measures

In this chapter, the environmental impacts of fire, biological control, chemical control, mechanical control, manual control, soil enhancement, reseeding / inter-seeding, grazing management and pruning for post-harvest treatment purposes will be discussed based on four main indicators: Air, water, land and biota.

Fire

Air

The burning of savanna biomass is a considerable contributor to GHG **emissions** in Africa, which affects the total emissions and thus global warming and climate change (UNEP n.d.). Emissions from burning biomass include CO_2, nitrous oxide and methane emissions, as well as volatile organic compounds and chemically active gases (e.g. nitric oxide and carbon monoxide) (Koppmann et al. 2015). Although fire is a natural phenomenon, the GHG emissions issue is high on the international political agenda (Pers. Comm. Michael Dege).

Dust and other aerosols accumulating in the air after a fire can have a cooling effect on an area by reducing both incoming and outgoing radiation (UNEP n.d.). However, local **air quality** can be affected by the smoke created by fire and the volatilisation of nitrogen creating ozone and aerosols that can cause disease (Lipson et al. 2011, Koppmann et al. 2015). Some of the gases emitted during a fire (e.g. sulphur oxide and nitrogen oxide) can react with water and oxygen in the air and cause acid rain. The particles can be transported across long distances by wind and have adverse effects on human health (UNEP n.d.).

Water

Studies on the impact of fire on water yield are inconsistent and should be assessed in the Namibian context. Studies from South Africa indicate a limited or slightly higher water yield in dry conditions by burning dormant vegetation. However, if plants are burned during active growth and when water availability is high, the water losses can be considerable. The impact on the water balance in the long-term depends on vegetative regrowth and climatic conditions: If most of the vegetative cover is destroyed, both the interception of rainwater by trees and bushes as well as water lost through evapotranspiration is reduced and more soil water is available for storage. The retention of water in a catchment can increase due to vertical and horizontal water flows. Increased heat from uncovered soils and removed vegetation cover can increase soil evaporation reducing storage of soil water and infiltration (Booysen & Tainton 1984).

Land

Everson & Everson (2016) suggest that a good fire regime in the dormant season is necessary to maintain the productivity of grasslands in the long-term. Fire can have different impacts on the **nutrient content and cycling** of soils (Booysen & Tainton 1984). Fire can increase the availability of nitrogen through increased mineralisation, which can encourage plant growth (Booysen & Tainton 1984, Heisler et al. 2004) and affects the spatial distribution of nitrogen in an ecosystem (Hobbs et al. 1991). Fire can also lead to the volatilisation of nitrogen, which can be a considerable loss of nitrogen for the system (Turner et al. 1997). If nitrogen is not volatised during a fire it can concentrate in the ash increasing the absorption of nitrogen by plants. Inorganic phosphorus can also be available in ash (Anderson et al. 2007). Nitrogen fixation after fire can compensate for nitrogen losses during fires e.g. through increased microbial or higher plant activity (Booysen & Tainton 1984). Potential initial losses of nitrogen through fire are compensated by nitrogen fixation and deposition in the long-term (Coetsee et al. 2008).

Generally, if an area is high in a specific mineral, burning can increase the concentration of that mineral in the soil (Booysen & Tainton 1984, Nepolo & Mapaure 2012). The ash from burning materials high in basic cations such as phosphorus, magnesium, calcium and potassium can neutralise soil acidity. Burning tends to increase their concentrations in the upper millimetres of the soil (Booysen & Tainton 1984).

In some studies, increases of **organic matter** after a burn were measured, which are mainly ascribed to the aggregation of charcoal (Booysen & Tainton 1984). Very hot fires with surface temperatures exceeding 690 °C can destroy 99% -which is very rare- of soil organic carbon and all surface litter. There is a substantial decrease of organic matter in very sandy soils with 8% clay content (or lower) under frequent burning (Booysen & Tainton 1984). In sandy soils, cation exchange capacity depends on organic matter which can be impacted by very hot fires (which are rare). The release of cations (such as phosphorus, magnesium, calcium and potassium) during a fire can increase **pH** in the upper soil layers. These increases are normally temporary and depend on the amount of ash, its chemical composition, soil texture, original soil pH and rainfall (Booysen & Tainton 1984).

Due to positive impact on nutrient cycling, fire can increase the net **primary productivity**. A study in the grasslands of South Africa, indicate a 20% lower productivity in unburnt areas (Everson & Everson 2016). However, burning during the summer months when grass is actively growing can have a disastrous impact on productivity (Booysen & Tainton 1984). For bush control, fires are therefore prescribed during the dry season (Van Oudtshoorn 2015; Rothauge 2017).

Studies in South Africa suggest that even high-intensity fires only have a very short-term and limited impact on **microorganisms** since soil temperature only increases in the first 15mm of the soil (Booysen & Tainton 1984). The impact of fire on fungi, actinomycetes and bacteria depends on local conditions as well as the maximum temperature, duration of heating and moisture content of the soil. Nitrifying bacteria may be very sensitive to heat. However, in some cases, the fixation of nitrogen by non-symbiotic microorganisms increases following a burn (Booysen & Tainton 1984). A study by Anderson et al. (2007) indicated a strong negative impact of fire on mycorrhizae, which colonise grassroots, caused by water runoff, soil crusting and lower soil moisture after frequent fires (Anderson et al. 2007).

Exposing the soil by removing plant cover can have an impact on the microclimate of the soil. Increased temperatures and increased insolation can negatively impact the dryness of the soil and thus activities of termites and beetles. The structure of the soil, which is the arrangement of the solid parts of the soil and pore space, and its properties determines the **hydraulic conductivity** and thus infiltration of water into soils. The effect of fire on faunal activity, vegetative cover and the destruction of the litter layer can reduce infiltration and the hydraulic conductivity of the soil. In sandy soils, fire can even cause repellence - the development of non-wettable surfaces (due to the deposition of distallised organic aliphatic hydrocarbons to soil particles) (Booysen & Tainton 1984). In clayey soils, fire can encourage the development of crusts (Pers. Comm. Peter Erb). Fire does not directly influence the soil's moisture-holding capacity but can influence water storage capacities by reducing or removing the protective litter layer (Booysen & Tainton 1984).

Fire can cause **soil erosion**. The removal of vegetation by fire can encourage both wind and water erosion. Wind erosion of ash following a burn can lead to a considerable loss of nutrients from a burnt site. High fire intensities can destroy organic matter and weaken soil aggregates. This can promote the detachment of soil particles when it rains. In savanna and grasslands, fire temperatures are mostly not hot enough to destroy soil organic matter. However, fire can also cause erosion through the destruction of plant cover and surface litter responsible for stabilising the soil. Especially on steep slopes, slowly recovering veld and areas with low infiltration or crusted soils can fire cause erosion if all vegetation is removed. In very steep areas the removal of vegetation can cause landslides and landslip erosion (Booysen & Tainton 1984).

In the long-term, a well-designed fire regime can contribute to open savanna landscapes (Booysen & Tainton 1984; Pers. Comm. Paul Smit). It can be used to create a mosaic, enhancing biodiversity and preventing large-scale uncontrolled wildfires (Pers.Comm.: Peter Erb). Recently burned sites characterised by burnt trees and blackened soil can be aesthetically displeasing. However, shortly after a fire, fresh nutritious grass attracts wildlife in a spectacular way which can be a considerable attraction (Booysen & Tainton 1984). Abandoning a regular fire regime can cause the bush to become even thicker (Pers.Comm.: Peter Erb).

Biota

The maintenance of spatial heterogeneity of the vegetation is important for the diversity and productivity of ecosystems. The uniform application of fire and grazing can decrease the spatial heterogeneity and thus species richness (Fuhlendorf et al. 2006).

Studies in South Africa suggest the following successional stages after a burn:

(1) The rapid return or survival of unspecialised feeders, that is tolerant of low biomass and open habitats. Directly after a fire, population density, species richness and biomass are often reduced. Species that are tolerant of sparse vegetation and occupying broad food niches tend to dominate assemblages.

(2) The temporary increase of opportunistic species taking advantage of the nutritious regrowth.

(3) Increasing population densities and species richness as the structural diversity of vegetation and thus habitats improve. Some of the pioneer species disappear, while species with more specialised food niches appear.

(4) In the absence of fire for longer periods, species richness, density and overall biomass declines (observed in South African montane grassland and fynbos) until it increase again in the future once a new equilibrium has been reached and a new community has developed (Booysen & Tainton 1984).

Since fires are a natural phenomenon in savanna ecosystems, most species are adapted (pers. comm.: Peter Erb). The green growth attracts large numbers of various birds and herbivores, for example, large ungulates, tortoises and lagomorphs (Booysen & Tainton 1984, Fuhlendorf et al. 2006). Archibald et al. (2005) suggest that patches can recover to their full biomass within one growing season (Archibald et al. 2005). Opening the landscape with fire encourages grazers -displaced by bush thickening- to return (Booysen & Tainton 1984; Smit & Prins 2015). Browsers (e.g. Kudu) move into an area once woody plants and forbs re-sprout. The number of animals aggregating on burnt land peaks after 10 to 30 days when peak grass growth is achieved. Other species also respond opportunistically to improved food availability (e.g. honey badgers excavating rodent borrows) or taking advantage of the minerals in the burnt plant material (e.g. elephants and plain's zebra eating burnt Mopane twigs) (Booysen & Tainton 1984).

Some birds may be triggered to breed earlier due to the improved availability and higher concentration of food. In South Africa, some birds seem to prefer to breed on recently burnt sites and are adapted to burnt conditions (e.g. blackwinged plover, bronzewinged courser, Temminck's courser, pennantwinged nightjar and dusky lark). Their regional movement seems to depend on the burning of the landscape. Some insects are also attracted to freshly burnt sites to deposit their eggs (Booysen & Tainton 1984).

Termites foraging in the wood and not in the soil may be killed during a fire. The foraging activity of termites was reduced after burning, probably due to the high surface temperatures of the exposed soil, desiccation of the soil and reduced food availability. Mortality among flightless arthropods may also be high. Especially arboreal insects do not survive fires well. Grasshopper eggs in the soil tend to survive fire, but young nymphs are often killed. However, most insect populations recover quickly after fires by larvae development from eggs in the soil or immigration. Amphibians and reptiles mostly avoid fire due to their moist habitat preferences or by escaping underground and into water. The lack of cover, increased predation and lack of food can lead to declines in small mammal populations following a burn. However, other studies have reported an increasing diversity of rodents in recently burned sites feeding on tree seeds that survived, while other species migrated to burned areas within a few months after the burn when green shoots emerged. There may be high mortality of slow-moving vertebrates such as tortoises or juveniles of larger mammals that cannot escape. The timing of fire plays an important role in reducing the mortality of juvenile mammals, which are mostly born in late spring or summer and thus after the burning season. The same applies to the breeding of birds. Most vertebrate species move faster than fire and can escape (Booysen & Tainton 1984). The immigration of species into unburned areas can influence the social organisation of species in that area, especially for territorial animals. However, it can also lead to the formation of new territorial associations (Booysen & Tainton 1984) improving genetic exchange between subpopulations.

Fire influences the vegetation and thus **structure of savannas**, which influences the microclimate, distribution of nutrients and moisture and biodiversity (Higgins et al. 2007). Generally, fire as a management tool favours the maintenance and development of grassland vegetation by preventing smaller trees and bushes to mature to a fire-resistant stage (Booysen & Tainton 1984, Sheuyange et al. 2005). Fire can be very effective in killing saplings and juvenile trees (Hannan et al. 2008, Holdo 2005, O'Reilly et al. 2006, Zimmermann & Mwazi 2002) and can influence the biomass and size structure (Higgins et al. 2007, Van Langevelde et al. 2003) by limiting seeds to escape the flame zone, which is species-specific (Higgins et al. 2000, Holdo2005). The fire can also promote the growth of grasses by removing moribund material altering the microclimate and nutrient levels in the soil (Nepolo & Mapaure 2012). Burning very late to trigger a flush of grass is unacceptable as it can have long-term effects on plant reserves (Pers. Comm.: Peter Erb).

Fire can encourage larger trees to coppice by destroying aerial portions of trees and bushes, while dormant buds are located at the base of the stem. Woody plants often re-sprout heavily after a fire, increasing the number of stems and reducing the stem circumference (Higgins et al. 2007, Kennedy & Potgieter 2003, Zimmermann & Mwazi 2002). High-intensity fires can also encourage the germination of seeds. Passing through ruminants has the same effect (Booysen & Tainton 1984).

Management Considerations

Fire is a natural phenomenon in savanna landscapes and a widely accepted management tool due to its potential to control woody plants and has shaped the nature of vegetation over time. The use of fire depends on the management objectives, management systems, local legislation and the response of plants in a specific area (Booysen & Tainton 1984). Fire can be used for the following objectives:

1) Removing excess vegetation,
2) Reducing the fuel load and chances of accidental fires,
3) Achieving or maintaining a desired plant composition,
4) Improving the nutritional value and acceptability for browsers and grazers,
5) Controlling livestock parasites,
6) Conserving water or soils in catchment areas,
7) Stimulating an out of -season flush of growth,
8) Creating habitats for different species.

To minimise the adverse ecological effects of fire, the interval between burns is vital. The longer the interval between two burning events, the more time to accumulate an adequate fuel load is available for high-intensity fires. In areas with higher rainfall of above 600mm, the bush-grass ratio can be maintained by fire alone since enough fuel is available for frequent fires burning seedlings, saplings and coppice. In areas with rainfall below 600mm, fires are less frequent due to a lack of fuel and cannot control coppicing but can control seedlings (Joubert et al. 2012). In these cases, fire can keep bush at an adequate height for browsers (Booysen & Tainton 1984).

Fire intensity considerably influences the reaction of the vegetation (Booysen & Tainton 1984). In areas with heavier soils, the impact of fire seems to be higher than in areas with lighter soils, reducing the basal cover and shifting the balance from perennial to annual grasses (Booysen & Tainton 1984).

The seasonality of fire is crucial. Too early burning can encourage bush thickening and destroy the grass layer. Ibo Zimmermann suggests that it should only be applied if the previous rainy season was good and there is enough soil moisture left to grow the grass (Pers. Comm. Ibo Zimmermann). A fire regime should mimic nature and start in September / October with early rains and the build-up of moisture (Pers. Comm. Peter Cunningham).

Animals should control the amount of grass creating natural fire breaks. Thus, enough fuel should only accumulate in areas which are not liked by animals, and fire will then improve the grazing. The subsequent grazing will reduce fire in the area for the next years (Pers. Comm. Ibo Zimmermann). Thus, grazing management and the use of fire are interlinked. Fire alters the foraging pattern, which affects grazing, while grazing can reduce fuel loads and change the patterns of fire in a landscape (Archibald et al. 2005). The grazing management applied after burning an area is critical. Grazing shortly after a burn can considerably damage the veld and the risk of overuse after a burn is high. The land should receive some time to rest following a burn (Booysen & Tainton 1984). Grazing should be managed to ensure an adequate fuel load can accumulate for intense follow-up fires to avoid the re-encroachment of bush and create an open system in the long-term (Van Langevelde et al. 2003).

Bigger areas should be burned to reduce grazing pressure and the fire should be very late dry season or beginning of the growing season when lightning would naturally occur (Pers. Comm. Ibo Zimmermann) since burning must be conducted while the grass is dormant. However, this is also rainfall dependent and may not apply to the higher rainfall areas (Pers. Comm. Peter Erb). The effect of fire on actively growing grass can have a very negative impact on the basal cover of grass and productivity (Booysen & Tainton 1984).

Burning on a rotational basis throughout the year can ensure the provision of short green grass all year. The grass regrowth after burning is high in protein, crude fibre, phosphorus and potassium. The grass regrowth after a fire is highly favoured by herbivores and prone to overutilization (Booysen & Tainton 1984, Hobbs et al. 1991). The use of fire can eliminate important food supplies in the short- or long-term (Booysen & Tainton 1984). In the case of larger farms, more than one block or camp should be burned per year to ensure habitat for species with small home ranges (Booysen & Tainton 1984).

Fire can encourage coppicing that can be used by goats to control bush regrowth or maintaining the plants in a productive condition for commercial use (Booysen & Tainton 1984). The reduction of woody vegetation by browsers can encourage the growth of grasses, which can increase the fuel load for future high-intensity fires (Van Langevelde et al. 2003). Fire can significantly reduce the canopy height and make it available for browsers (Booysen & Tainton 1984).

Fire needs thorough planning, preparations and fire-fighting equipment, approval from neighbours and carries the risk that it may spread (SAIEA 2016). To minimize damage to desirable larger shrubs and trees, fires for aftercare purposes should be of intermediate intensity (Rothauge 2017). This can be achieved by burning only during the cool time of the day, when fuel loads are not > 1500kg DM/ha and when the wind is calm. It is always best to burn as far as possible with the wind (some backfires are necessary to contain the fire on the downwind side of the burned area). The effect of fire can be drastically enhanced if combined with foliar spraying of coppicing plants (regrowth must be at least knee-high) and seedlings, as well as in combination with intensive browsing, e.g. with goats and/or browsing game (Booysen & Tainton 1984, Jordaan & Le Roux undated).

Biological Control

Air

Based on IPCC estimates, goats only contribute 0.6% to global emissions. Most ruminants are a source of CO_2 and methane emissions. The digestive process of ruminants emits more methane than monogastric species, although goats tend to emit comparatively less methane than other livestock such as cattle (Lipson et al. 2008). A study by Herrero et al. (2008) on **emissions** in Africa estimate that goats produce about 7.5% of methane emissions of African domestic ruminants (cattle = 84%) and have a better production value per volume of GHG emissions among livestock (Herrero et al. 2008). Nitrous oxide, which has 300 times the global warming potential of CO_2, can also be emitted from manure. The emissions are even higher when browsers are combined with fire as a management tool (Lipson et al. 2011).

Volatilisation of nitrogen and the subsequent release from manure can influence the **air quality**. The volatilisation process can create ozone and aerosols that can cause cancer, cardiac and respiratory diseases (Lipson et al. 2011).

Water

Goats require considerably less water (per kg) than other livestock (Lipson et al. 2011).

Trampling by browsers can destabilise stream banks and affect water quality by increasing sediment loads. The manure from goats can also contribute to water pollution under specific circumstances but is of no concern in extensive systems (Lipson et al. 2011).

Land

Rothauge estimated in 2003, that around 20 – 50% of Namibia's commercial farmland is already influenced by bush thickening reducing the carrying capacity by 20 – 90%. The degraded rangeland makes it more suitable for browsers such as goats, which can potentially control bush thickening after initial thinning (Rothauge et al. 2003). Goats can positively contribute to nutrient cycling by depositing nitrogen through urinary and faecal excrete. Soils fertilised with manure are often more biologically active and fertile (Lipson et al. 2011, Schmitz 2008).

High stocking densities and the resulting trampling can affect the soil structure, which can increase runoff and erosion (Lipson et al. 2011).

Biota

Goats and pastoralism in general can create habitats for species that prefer open pasture (Lipson et al. 2011). Browsing can control weeds and bush and thus increase the abundance and diversity of local grass species (Lipson et al. 2011). Research at Omatjenne Research Station, Namibia, showed that two weed species were eradicated in camps stocked with goats, but not in camps stocked with cattle at a comparable stocking rate (unpublished data, Wolfie von Wiellich). The use of goats for post-harvest management of bush can have positive effects on species composition by removing unwanted biomass (Du Toit 1972, Lipson et al. 2011). At Omatjenne, the basal cover of perennial grasses increased when goats were stocked at 0.86 goats/ha and decreased with heavily stocked cattle treatment (5 ha/LSU; Zapke 1986).

Goats can considerably reduce canopy cover and the density of woody plants, which can lead to mortality of plants up to 1.7 m high (Sweet & Mphiyane 1986). Spinescent species belonging to the *Senegalia/Vachellia* genera, however, tend to be more resistant to browsing by goats, which can have undesirable effects on the woody species composition (Van Oudtshoorn 2015). In the same trial at Omatjenne mentioned above, goats decreased *Dichrostachys cinerea* numbers from 500/ha in 1964 to 56/ha in 1977, *Senegalia mellifera* numbers increased slightly (487/ha vs. 555/ha), while *Vachellia reficiens* numbers strongly increased (17/ha to 144/ha) over the same period. Desirable fodder-bush numbers also declined substantially over this 13-year study period (Zapke 1986). Thus, palatable fodder species were severely suppressed by over-browsing before *Senegalia/Vachellia* encroacher bush was controlled by the goats (Rothauge 2017).

Biocontrol can contribute to biodiversity by reducing invasive encroaching species that could threaten other species (Randall & Tu 2001). **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). The risk of non-target control by insects is limited based on trials on Australian invasive *Acacias* in South Africa (Zachariades et al. 2017).

Fungi often have a relatively strong impact on vegetative growth and can potentially affect useful attributes of the targeted species (Impson et al. 2011).

Management Considerations

Goats require very high levels of management to be successful (Pers. Comm. Bertus Kruger). These include tight control over diseases, parasites, predators, theft and providing special care during the lambing season (Pers. Comm. Wolfie von Wiellich). If goats range freely, they are unlikely to exercise the browsing intensity required to control woody plants. They must be kept in the target area long enough and at an appropriate stocking rate to have any effect (Smit n.d., Raats 1998). Special infrastructure such as goat-proof fences is needed to maintain a high browsing pressure (Van Oudtshoorn 2015). Alternatively, goats can be herded (Pers. Comm. B. Kruger).

An annual stocking rate of 1 goat/ha appears to be too low to control *Senegalia/Vachellia* encroacher species but may be effective for *D. cinerea* at low densities (I.e. 500 plants/ha) (Zapke 1986). A stocking rate of 2 goats/ha stocked continuously (Pers. Comm. Wolfie von Wiellich) or 10 goats/ha for a short duration in a rotational browsing system (Pers. Comm. Axel Rothauge) may be more appropriate. Higher rainfall areas probably require even higher stocking rates. Especially in areas with dense bush and thus fast regrowth, browsing pressure may not be high enough to control further degradation (Rothauge et al. 2003) and will have to be supplemented by other measures to control regrowth.

Goats confined to an area to control bush will increasingly consume grass as bush regrowth and forage become less available (Raats 1998, Rothauge et al. 2003). Some studies reported limited damage to grasses if goats at high stocking densities are restricted to the dry season (Sweet & Mphinyane 1986). Incorporating browsers into a post-harvest treatment programme can provide an additional source of income for the landowner, which can be substantial if well managed (Pers. Comm. Wolfie Von Wiellich).

Wild Browsers will also benefit from the available browse, but their impact is difficult to manage with conventional control measures such as fences. It can partly be controlled by providing water points and licks but will mostly result in uneven use creating a patchwork effect. Burning becomes a vital management tool if this measure is used to remove unwanted and unpalatable vegetation and relieve other heavily used areas (Booysen & Tainton 1984). Due to the difficulties around controlling stocking rates and thus their impact on the woody component, they should not be relied on as the primary post-harvest method (Pers. Comm. Peter Cunningham).

Scrub Hares (and other lagomorphs) browse on seedlings and small shrubs. In a Namibian field experiment, Joubert et al. (undated) showed that hares increasingly browse *Senegalia mellifera* seedlings during the dry season and that browsed seedlings have a higher mortality rate. They concluded that small browsers such as scrub hares can play an important role in regulating savannas. Maintaining a healthy hare population can assist in controlling seedlings, but they cannot eradicate bush species (Pers. Comm. Peter Cunningham).

Insects are unlikely to reduce the densities of bush if used as a single method. However, the ability of some insects to reduce seed agents can considerably limit the expansion of encroachers (Impson et al. 2011) and can be valuable if used in conjunction with other methods. The full potential of biological control with insects can thus only be realised through an integrated approach with other measures. In South African studies, using insects after mechanical clearing has been successful to control, for example, alien *Acacia* invaders, but not indigenous encroacher species. The combination ensures the destruction of plants and suppressed seed production (Impson et al. 2011).

Mechanical Control

Air

If large machinery is used to treat an area after initial bush control the vehicles produce emissions. The dust created due to the considerable disturbance of the soil can have a negative impact on air quality.

Water

Soil compaction caused by heavy machinery can reduce the infiltration of rainwater into the soil with potential negative impacts on groundwater recharge. It also increases the risk of soil erosion by increasing surface runoff.

Land

Bush thickening tends to increase soil organic carbon and it is therefore expected that after harvesting the content of soil organic carbon will slowly decrease over time. Soil organic carbon decomposes slowly and can take several decades. Post-harvest measures such as rolling may speed up the decomposition rate of woody material, because of the closer contact of the rolled woody material such as stems, branches and twigs with the soil surface (Seebauer et al. 2019).

The highest concentration of nutrients and organic material is found in the topsoil layer (Brady & Weil 2002), which is easily disturbed by heavy machinery enhancing re-invasion (Tu et al. 2001). The use of heavy machinery can facilitate the loss of soil nutrients (Commonwealth of Australia 2004) and destroys the existing perennial grass cover, which must re-establish on bare soil. Damage to the grass layer can considerably reduce the carrying capacity until the grass layer recovers (Welch n.d.).

Also, heavy machinery can cause soil compaction, which destroys the soil structure and reduces porosity, water and air infiltration, nutrient uptake by plants and increases the resistance for root penetration (Brady & Weil 2002; Wolkowski & Lowery 2008; Honsbein et al. 2012). Due to the reduced infiltration rate, there is an increased risk of soil erosion due to runoff (Brady & Weil 2002). It also increases the conductivity of heat into the soil profile (Brady & Weil 2002). Where heavy machinery has also been used in the harvesting process itself, compaction and disturbance by heavy machinery post-harvesting can have cumulative effects.

Biota

The structural diversity of the landscape (horizontally and vertically) may influence animal diversity directly, as well as indirectly (Tews et al. 2004). Non-selective measures such as heavy machinery and, to a lesser degree, soil-applied arboricides have less potential to create a complex habitat structure involving many height strata and horizontal heterogeneity. Removal of the large trees will specifically affect species such as large raptors, vultures and Sociable Weavers (*Philetarius socius*) that require nesting and perching sites (Dean et al. 1999, Cunningham 2018). Mechanical post-harvest methods using heavy machinery potentially could kill slow-moving animals such as tortoises, chameleons and crawling invertebrates, as well as immobile juveniles. Reptiles are among the groups potentially most affected by bush clearing with heavy machinery (Cunningham et al. 2018).

Burrowing species may also be negatively impacted by caved in burrow openings or compacted topsoil layers making future burrowing more difficult. After severe soil disturbance -e.g. from ploughing- invertebrate abundance and biomass was considerably reduced in an Australian study. The disturbance can transport fauna from the lower levels of the soil to the surface, where they are more exposed to drought and other climatic forces (Liu et al. 2016). Mammals and birds are less impacted, because they can migrate. However, some species are associated with a bush thickened state. Excessive clearing can have a negative impact on browsers and birds, which are dependent on the bush for fodder, shade, shelter and nesting. Large trees and a mosaic of vegetation should be maintained to cater for different habitat preferences (Cunningham 2018).

Mechanical post-harvest measures using heavy machinery potentially could kill or damage scarce and protected trees and other plants, because of its low selectivity. Some invasive species -such as prickly pear- may be encouraged to establish themselves after some mechanical controls using heavy machinery (Welch n.d., Cunningham 2018).

Disturbance can also encourage the establishment of encroachers (Smit n.d.) by preparing a seedbed with little initial herbaceous competition. When uprooting plants, some roots can re-sprouting heavily and often changing their form from single- to multi-stemmed growth forms. The grass layer can also be destroyed by considerable soil disturbance. Re-seeding may be necessary as a follow-up treatment (Welch n.d.). After the disturbance, annual grasses establish themselves first (Welch n.d.).

The removal of riparian vegetation must be carefully assessed to allow for the movement of wildlife and the stabilisation of soils to avoid erosion from flash floods (Cunningham 2018). Another big concern is the removal of large trees or protected species (Pers. Comm. Michael Dege).

Some mechanical methods are very selective and can minimise damage to desirable plants (Tu et al. 2001). Deeper ploughing of the soil can transport nutrients to lower layers of the soil increasing the availability of these nutrients to organisms in the lower soil layers (Liu et al. 2016).

Management Considerations

Natural competition between plants is one of the best ways to control bush thickening and keep bush levels at a manageable level. The initial control method should not remove all vegetation to support the effectiveness of post-harvest treatment plans (Commonwealth of Australia 2004).

The use of **heavy machinery** in post-harvest operations is not recommended due to the high soil disturbance and soil compaction expected. Compaction is especially a problem when heavy machinery is used under wet conditions (water content above field capacity) (Wolkowski & Lowery 2008, Brady & Weil 2002). It is important to distinguish between topsoil and subsoil compaction, which are equally undesirable. Machinery with an axle load exceeding 10 tons can cause compaction of the sub-soil layer. Tyres with a large footprint cause lower topsoil compaction, but subsoil compaction is caused by the total load of the machine, not soil-area contact (Wolkowski & Lowery 2008). Compaction is more likely in soils with low organic content (Wolkowski & Lowery 2008). Wet, clayey soils are the most prone to compaction, but sandy soils that do not form aggregates can also be compacted (Wolkowski & Lowery 2008). Namibian soils tend to have a low organic content and large parts are covered by sandy soils with a weak structure.

Regrowth may also be removed mechanically or manually for other purposes, e.g. where the young new growth is cut or mulched for use as roughage in **bush feed** (Honsbein et al. 2017). The repeated removal of regrowth, especially the foliage, will drain the ecosystem of nutrients in the long run (browsing animals, on the other hand, recycle nutrients through dung and urine).

Manual Control

Air

Manual control has no substantial impact on emissions, apart from the cars used to transport workers to the site and the removal of carbon from harvesting the bush.

Water

Due to the selective nature of manual control, impacts on the water budget are limited.

Land

Using manual or semi-mechanised measures for post-harvest control may disturb the soil and trample vegetation supporting re-encroachment (Lesoli e al. 2013), but this will be considerably less compared to heavy machinery.

Biota

Manual methods are very selective and can minimise damage to desirable plants (Tu et al. 2001). However, the impact depends on the activities of the harvesters and their knowledge of sustainable harvesting and potentially harmful impacts. The structural diversity of the landscape (horizontally and vertically) may influence animal diversity directly, as well as indirectly (Tews et al. 2004). If habitat diversity is considered when manually removing trees and bushes, the impact can be minimal. Excessive clearing can have a negative impact on browsers and birds, which are dependent on the bush for fodder, shade, shelter and nesting. Large trees and a mosaic of vegetation should be maintained to cater to different habitat preferences (Cunningham 2018). The removal of large trees or protected species is a big concern (Pers. Comm. Michael Dege).

Large numbers of field workers can impact local fauna, especially tortoises, monitor lizards, etc. as these are collected and consumed as food or collected for illegal trade. This could have a considerable impact on these species if not controlled (Pers. Comm. Peter Cunningham).

Labour intensive post-harvest measures such as manual-mechanical control will increase the chance of illegal collection of protected plants by the workforce. There may also be disturbance to the wildlife in the area to be controlled.

Management Considerations

Seedlings and saplings can be removed **manually** (Dannhauser & Jordaan 2015; Rothauge 2017). Physically removing larger coppiced plants is labour intensive as many encroacher species must be removed to a depth of at least 20cm below ground (Walter & Volk 1954 in Strohbach 1998/1999). Slashing the aboveground parts is usually ineffective, except when done repeatedly in a single season (i.e. 4 times/annum, Teague & Killilea 1990), and perhaps also in the case of seedlings, which are more vulnerable to physical damage.

Regrowth may also be removed mechanically or manually for other purposes, e.g. where the young new growth is cut or mulched for use as roughage in **bush feed** (Honsbein et al. 2017). The repeated removal of regrowth, especially the foliage, will drain the ecosystem of nutrients in the long run (browsing animals, on the other hand, recycle nutrients through dung and urine).

Chemical Control

Air

Spraying chemicals can cause chemical drift carrying the chemicals off-site. This effect is exacerbated under windy conditions (Commonwealth of Australia 2004).

If applied under unfavourable conditions, up to 80-90% of herbicides can be volatilised into the atmosphere. They volatilise more quickly from moist soils (Honsbein et al. 2012).

Water

Using arboricides for post-harvest control can potentially contaminate groundwater sources (Rothauge 2017), especially where soil-applied arboricides are used. Even the runoff from water used to wash equipment can kill non-target plants (Rothauge 2017).

The use of chemicals should be avoided near waterways because they can travel off-site through spray drift, runoff and by infiltration into groundwater posing a considerable risk to water users and aquatic diversity (Commonwealth of Australia 2004). Especially tebuthiuron is very soluble and can easily be transported off-site by runoff or by leaching through the soil -especially if applied shortly before rainfall events. Bromacil can also leach into groundwater -especially in sandy soils. Tordon and 2,4-D are also easily leached in soil (Honsbein et al. 2012, Dube et al. 2011). Rothauge (2017) mentions a case in the Dordabis area where large riverine trees died 15 years after the use of a soil-applied arboricide upstream.

Land

Soil-applied arborocides can have an impact on soil microbes and arthropods, which can impair soil functions (e.g. nitrogen cycling and organic matter decomposition). A lower number of microbial species in a specific niche can reduce soil fertility (Honsbein et al. 2012). Bromacil, a widely used soil-applied active ingredient, can be toxic to soil microbial biomass at high concentrations, which can initially delay the breakdown of the active ingredient in the soil. Low residues, however, can enhance soil microbial activity (Honsbein et al. 2012). Certain arboricides suppress organisms involved in the decomposition of standing dead wood, as chemically killed tree and bush take longer than usual to decompose (Rothauge 2017).

Arboricides such as Bromacil are not absorbed by soil colloids and is transported in the soil profile by leaching and lateral soil water flow. It persists in the soil for about a year (Lesoli et al. 2013). The half-life of different chemicals used in arboricides ranges from 1 month for 2,4-D to over 1 year for active ingredients including tebuthiuron and picloram (Lesoli et al. 2013). The half-life can be extended in dry areas with limited soil moisture and a high soil pH (Lesoli et al. 2013), which characterize many Nambian soils.

Post-harvest control using soil-applied arboricides should preferably not be used where soil-applied arboricides were recently used (1-2 years ago), to avoid cumulative effects. 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).

Biota

The dead plant material left after chemical control can favour some invertebrates by improving the habitat and facilitating microbial activity (Liu et al. 2016). However, non-selective measures such as soil-applied arboricides have less potential to create a complex habitat structure involving many height strata and horizontal heterogeneity. Soil-applied arboricides have a considerable impact on large trees, compared to other more selective post-harvest measures, impairing habitat structure (Tews et al. 2004).

Non-selective, soil-applied arboricides (e.g. tebuthiuron) can form persistent bare patches. These sterilised bare patches where arboricide residues are concentrated can remain bare of vegetation for extended times after treatment (Du Toit & Sekwadi 2012). Tebuthiuron, a commonly used soil-applied arboricide, breaks down slowly in the soil and remains toxic for a considerable period, especially under high-carbon or low rainfall conditions (Du Toit & Sekwadi 2012). For example, non-target trees died decades after arboricide use despite a short stated residual effect on the product label (Rothauge 2017). In a semi-arid environment, residues of tebuthiuron were also found in the foliage of trees more than a decade after application (Honsbein et al. 2012).

The local disturbance caused by soil-applied arboricides can create opportunities for weeds to establish, for example, the invasion of the undesirable bitter bush, *Pechuel-Loeschea leubnitziae* and *Laggera decurrens* (Honsbein et al. 2012). A study in the central parts of Namibia found that 24-30 months after bush control using soil-applied arboricides *Pechuel-Loeschea leubnitziae* increased relative to manually cleared sites, while absent in control (bush encroached) sites (Haussmann et al. 2016). In the same study, manual control of *A. mellifera* increased grass species richness (perennial species increased), while no change in richness in the soil-applied treatment sites (Haussmann et al. 2016). Controlling plants with chemicals can also encourage other problem woody plants to establish themselves and become dominant (e.g. sicklebush). The chemical treatment would then have to be followed up with even more chemicals (Pers. Comm. Stephan Bezuidenhout). Sickle bush (*Dichrostachys cinerea)* is particularly difficult to control - even with chemicals (Honsbein et al. 2012).

The active ingredients bromacil and tebuthiuron are not toxic or only slightly toxic to most animal species and are readily excreted through urine. Bromacil, the active ingredient of a commonly used soil-applied arboricide in Namibia, is considered non-toxic to mammals, birds and reptiles, but slightly toxic to fish and amphibians according to United States Environmental Protection Agency tests (Dube et al. 2011). Small amounts of bromacil ingested by cows were, however, traceable in cow milk and bromacil can be highly toxic if ingested by sheep (Honsbein et al. 2012). Tebuthiuron can be slightly toxic to small mammals if ingested and is highly toxic if inhaled (Honsbein et al. 2012). An Australian study suggests that the use of herbicides can increase the abundance of soil invertebrates due to the increase in plant residues. Most herbicides and arboricides also appear to have negligible effects on ants and arthropods (Liu et al. 2016). However, it was suggested that chemicals can have a considerable effect on micro-fauna, which can cause offsite effects along trophic chains thereby affecting entire ecosystems (Pers. Comm. Stephan Bezuidenhout).

Management Considerations

How arboricides are spatially applied influences the stability of the woody component after the treatment. A study in the Northern Cape province of South Africa showed that the broadcast application of a soil-applied arboricide (tebuthiuron) resulted in a significantly higher seedling establishment of encroacher species compared to the selective, manually applied arboricide (also tebuthiuron) (Harmse et al. 2016). If no disturbance such as a fire event interferes, the broadcast treatment was predicted to transition back to an encroached state, while the selective treatment, characterised by a higher structural diversity, appeared much more stable (Harmse et al. 2016).

Soil applied chemicals are non-selective and may potentially kill sensitive, non-target plants (Van Oudtshoorn 2015; Rothauge 2017). Rothauge (2017), for example, recommends that soil-applied arboricides should not be used closer than 50m from protected trees. An exception appears to be the protected tree species *Boscia albitrunca*, which are less likely to be affected by soil-applied arboricides such as Tebuthiuron (Bezuidenhout et al. 2014).

It is also important to consider potential health and safety concerns of arboricides leaching into drinking water supplies and consumed by livestock, which could affect human and animal health.

Grass Re-seeding & Inter-seeding

Air

Re-seeding can increase the abundance of desired grass species, which absorb CO_2 from the atmosphere. Studies conducted in a semi-arid environment in China, suggest that the carbon sequestration potential in landscapes with abundant grass is higher than in bush thickened areas (Liu et al. 2020).

Grass can also act as a dust trap.

Water

Reseeding of grasses resulting in a perennial grass cover can reduce runoff of water and increases infiltration rates (Van Oudtshoorn 2015; Mangani et al. 2018; Meyer 2020).

Land

Seeding can have positive local impacts on light levels and nutrients in the soil (Commonwealth of Australia 2004).

Biota

By restoring vegetation structure, seeding can enhance the habitat for wildlife (Commonwealth of Australia 2004). Depending on the species used, grass reseeding may increase species richness and the productivity and quality of grazing (Rothauge 2017). Sowing of perennial grasses can increase competition and thereby reduce bush densities (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). Seeding can help to restore vegetation structure and floristic diversity (Commonwealth of Australia 2004).

After reseeding and allowing the land to rest for one year, an Australian study found significant increases in the abundance and biomass of invertebrates (Liu et al. 2016).

However, reseeding can also shift the soil invertebrate fauna towards predators with a larger body size and reduce the abundance of prey groups (Liu et al. 2016).

Reseeding can introduce invasive or unwanted species unintentionally if present in the seed mixture (Van Oudtshoorn 2015). Commercial grass seeds are usually selected for certain traits such as high performance under planted pasture conditions, therefore, may not be adapted for the restoration site's environmental conditions (Van Oudtshoorn 2015). These cultivars can potentially contaminate the gene pool of indigenous species.

Management Considerations

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 site 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.

Soil Enhancement

Air

Spreading woody ash at a large scale can create a lot of dust (Saunders 2014).

The production of charcoal itself produces emissions.

Water

Brush packing can reduce runoff and increase infiltration rates (Van Oudtshoorn 2015; Mangani et al. 2018; Meyer 2020). By reducing the detachment of soil particles the risk of soil erosion is reduced (Eldridge et al. 2015). Brush packing also lowers evaporation by lowering the soil temperature and reducing wind speeds close to the ground (Van Oudtshoorn 2015, Meyer 2020). Thus, more water is available for plant growth under packed brush.

Charcoal and biochar amendments may increase soil water retention and aggregate stability, leading to enhanced plant water availability and reduced erosion (Zimmerman et al. 2020). In a study on the effect of charcoal additions on the available moisture in soils with different textures, soil water retention increased by 18% after a 45% (by volume) share of charcoal was added to sandy soils (Oguntunde et al. 2008). Conversely, on clayey soil the addition of **biochar** can decrease available moisture (Steiner et al. 2008).

Land

Experiments from North-West University show that **brush packing** in bush control experiments has a significant and positive impact on local grass biomass. The packed brush encourages seedling establishment, protects plants from large herbivores and the decomposing branches and trapped organic material enhance soil fertility (Pers. Comm. Ibo Zimmermann, NWU, n.d., Mangani et al. 2018; Meyer 2020).

Brush packing will prevent both wind and water erosion (Van Oudtshoorn 2015). Creating parallel rows on the contour may be the most stabilising arrangement of packed brush (Rothauge 2017). Brush packing will reduce chances of wind erosion by reducing wind speeds close to the ground.

Animals kept in the harvested area will retain most nutrients through nutrient cycling, provided they are kraaled inside the harvested area. **Kraaled animals** export nutrient from feeding places to the overnight kraal area, thereby altering the spatial distribution of nutrients in an area.

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 an agricultural soil amendment. It can raise the pH of the soil and add nutrients (Saunders 2014). 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). The ash from burning biomass should be returned to the soil to give some minerals back (Pers. Comm. Ibo Zimmermann). Application of wood ash on forest and agricultural soils can provide nutrients and increase soil pH (Buss, Jansson & Mašek 2019). Mixing of wood ash and wood-derived biochar, e.g. made from forest residues can be a good combination: the carbon providing general soil-improving effects and the ash providing nutrients. The wood ash contains high concentrations of K, Na, Ca and Mg, which are known to catalyse biochar formation and increase biochar yield (Eom et al. 2012). Woody ash can change the soil chemistry rapidly and temporarily, often resulting in reduced plant growth and potassium leaching (Buss, Jansson & Mašek 2019).

Charcoal (or biochar) 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 encourage 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., Jin 2010; Lehmann et al. 2011). Wardle et al. (2008) suggest that charcoal inputs to the forest litter layer may accelerate decomposition processes. Charcoal may also improve soil fertility by increasing plant-available phosphorous and calcium, increasing pH values, and by improving the cation exchange capacity of soil (Ward et al. 2008). Even after > 150 years of leaching, the concentration of bioavailable nutrients like K, Ca, Mg, Na, Mn, and Zn remain higher (Ding et al. 2016). Charcoal residues at historical charcoal production sites improved the carbon storage capacity of temperate soils (Borchard et al. 2014). Application of charcoal can improve the chemical properties of the soil by neutralising soil pH and increasing total nitrogen and available phosphate contents, cation exchange capacity, exchangeable cations, and base saturation. Moreover, it can decrease exchangeable Al ions, which are harmful to root growth (Nigussie, Kissi, Misganaw & Ambaw 2012). **Biochar** can improve soil physical properties including the increase of porosity and water storage capacity, as well asdecrease bulk density (Lu et al. 2014).

Biota

Brush packing can create refuges for small animals, including rodents and other small mammals, reptiles and invertebrates, thereby increasing biodiversity (Pers. Comm. Ibo Zimmermann). It creates a micro-habitat favourable for the recruitment and growth of grasses and protects new seedlings from herbivory (Kellner 2019). Thus, it can be expected to increase both plant and animal diversity as well as species richness.

Labour intensive post-harvest measures such as brush packing will increase the chance of illegal collection of protected plants and animals by the workforce.

Short duration overnight **kraaling** has a positive effect on grass quality and biomass.

Management Considerations

Mixing of wood ash and wood-derived biochar, e.g. made from woody residues, can be a good combination: the carbon providing general soil-improving effects and the ash providing nutrients. Wood ash contains nutrients such as K, Mg, Ca, P and micronutrients, while the organic part of the biochar increases the nutrient use efficiency by plants (Li et al. 2017) as well as increasing the water holding capacity of soils.

Brush packing should not be too deep, as this result in too much shade and poor plant establishment and growth.

Grazing Management

Air

Most ruminants are a source of CO_2 and methane emissions. The digestive process of ruminants such as cattle emits more methane than monogastric species (Lipson et al. 2008). Nitrous oxide, which has 300 times the global warming potential of CO_2, can also be emitted from manure.

Volatilisation of nitrogen and the subsequent release from manure can influence the air quality. The volatilisation process can create ozone and aerosols that can cause cancer, cardiac and respiratory diseases (Lipson et al. 2011).

Water

Grazing livestock and most game are water-dependent and require quality water to drink.

Nitrate leaching from manure can contaminate groundwater sources.

Land

Livestock can redistribute nutrients through their excreta thereby increasing the rate of nutrient cycling (SANBI 2014). Removing moribund material through grazing can stimulate grass biomass production by removing growth inhibitors (SANBI 2014).

Trampling by livestock can break up hardened soil surfaces encouraging a better infiltration of rain and germination of seeds (SANBI 2014). The weight of cattle, the hoof action and trampling can also cause damage especially on steeper slopes (SANBI 2014).

Large animals such as livestock can also compact soils (Wolkowski & Lowery 2008). With animal paths, the compaction tends to be vertical below the path (Nortjé 2013). The regular moving of cattle across the land can lead to erosion rills and potentially gulleys (SANBI 2014).

Grazing animals reduce the available fuel load and therefore reducing fire risk fire intensity, hence, nitrogen losses through volatilisation. They also conserve nitrogen with their excrete by moving it to below-ground pools. Thus, losses of nitrogen through fire are compensated by nitrogen fixation and deposition in the long-term (Coetsee et al. 2008).

Wind erosion is most prevalent in arid environments. The grazing management here should ensure that as much vegetation as possible covers the soil (Van Oudtshoorn 2015).

Feeding animals supplements such as kelp, fish wastes, gypsum, zinc or copper sulphate can improve soil fertility through the recycling of minerals back to the land. This can address mineral imbalances and encourages grass growth (Pers. Comm. Ibo Zimmermann).

Biota

Localised disturbance induced by grazing can create habitat variation and thus increase the abundance and richness of small animals (SANBI 2014). The stress caused by trampling can slow down bush thickening (Commonwealth of Australia 2004) and the deposited nutrients may favour the growth of grasses by improving soil fertility and their competitive ability.

Livestock competes with wildlife for grazing and some wildlife species may avoid areas stocked with livestock.

Livestock can transport undesirable plants from other areas on their fur, hooves and through droppings, encouraging expansion to new sites (Commonwealth of Australia 2004). In addition, heavy livestock grazing can damage desirable vegetation (Commonwealth of Australia 2004).

Selective or over-grazing can considerably change the species composition of grassland - especially in conjunction with poor use of fire (SANBI 2014).

Management Considerations

Continuous overgrazing is stated as one of the contributing causes of bush thickening (De Klerk 2004; Van Oudtshoorn 2015, Dannhauser & Jordaan 2015). How the grazing is managed has an impact on the regrowth and recruitment rate of the bush. Grazing can influence the effectiveness of post-harvest measures and, in turn, be affected by the type of treatment applied. Livestock can remove excess foliage to facilitate other post-harvest treatment measures (Commonwealth of Australia 2004).

Grazing and rangeland management can considerably contribute to control the re-encroachment of bush if well-managed and acknowledging overgrazing as a driver of bush thickening. Following bush harvesting or control, the area should be rested (no grazing) to allow perennial grasses to establish (Dannhauser & Jordaan 2015). To ensure a vigorous and competitive herbaceous layer, rest during the growing season is important. In a trial at Tawoomba, South Africa, woody density in camps grazed continuously or during the entire growing season was much denser after six decades, compared to the more open structure of camps grazed only in winter or only partially during the growing season (O'Connor et al. 2014). Alternatively, good grazing management must take into account rest periods of at least one season, which can have a considerable positive effect on the grass layer (Pers. Comm.

Ibo Zimmermann).

A grazing management plan should prioritise optimum stocking rates (Dannhauser & Jordaan 2015). Stocking rates should be adjusted according to the season's herbaceous production, with destocking during drought years (Pers. Comm. Bertus Kruger, Van Oudtshoorn 2015). Sheep are more effective than cattle in controlling woody seedlings and also tend to spread fewer seeds of undesirable species than cattle (O'Connor et al. 2014). The use of indigenous breeds (i.e. Nguni cattle, Damara sheep etc.), which utilise browse more than other species, should be considered (Pers. Comm. Peter Cunningham).

Where arboricides are used, livestock should not be allowed to graze in those areas until the risk of contact with the arboricide has diminished according to the product label or restrictions imposed by niche markets (Anonymous 2019).

Where fire is planned as an aftercare measure, livestock allowed in the area for a short duration will graze and trample under large trees and shrubs, because of the higher quality grazing and shade found underneath large canopies. This will lower the fuel load, thereby protecting the large trees and shrubs from fire damage (Zimmermann et al. 2008).

Pruning

Air

Similar to manual control there is no substantial impact on emissions, apart from the cars used to transport workers to the site. CO_2 emissions from the removal of biomass are less since the plant remains and only individual branches are removed. Thus, the carbon sink remains intact.

Water

Potential higher inception of rainwater and transpiration since a significant number of large trees remain in the landscape. However, the share provided by large trees can have a positive impact on soil moisture and evaporation from the soil.

Land

Trees can have a positive impact by enriching the soil under their canopies, especially larger specimens (Joubert & Zimmerman 2002). Some desirable grasses are associated with tree canopies and they provide an important sub-habitat for different grass species (Smit 2005).

Biota

Pruning and thinning can ensure that patches of woody plants are maintained contributing to habitat heterogeneity and species diversity (Joubert & Zimmermann 2002).

Management Consideration

Some experience and expertise are required to ensure trees and bush are pruned in a way that ensures re-growth in a desirable way. Information on pruning savanna trees and shrubs in a Namibian context is scant.

4. Risk Assessment Overview

Environmental impacts can be positive or negative and vary in importance and significance. The significance of impacts on the Air, Water, Land and Biota categories were assessed qualitatively for the individual post-harvest measures. The ultimate **significance of impacts** depends on the assessed *consequence* if an impact occurs combined with the *probability* of that impact occurring. The consequence is a function of the impact's severity, the spatial scale at which it occurs, and the duration of the impact, which were separately assessed as High, Medium, or Low. The plus (+) denotes a positive impact. The definitions used for assessing the intensity, spatial scale, duration and probability of impacts are listed below:

Definitions Adapted for Post-Harvest Measures

Significance	Consequence x probability
Consequence	Function of severity, spatial extent and duration

Intensity of Impact

H	Substantial deterioration. Recommended levels are violated. Irreplaceable loss of resources.
M	Moderate / measurable deterioration. Recommended level will occasionally be violated. Noticeable loss of resources.
L	Minor deterioration. Change not measurable. Limited loss of resources.
H+	Substantial improvement. Within recommended levels or better. Substantial increase in resources.
M+	Moderate improvement. Within recommended levels or better. Moderate increase in resources.
L+	Minor improvement. Change not measurable. Limited increase in resources.

Spatial Scale of Impact

H	Far beyond site boundary. Regional/national
M	Beyond site boundary
L	Localized - within site boundary

Duration of Impact

H	Long-term. >5 years
M	Medium term. 2-5 years
L	Short-term. <1 year

Probability of Impact

H	Definite / Continuous
M	Possible / Frequent
L	Unlikely / Seldom

Air

Considers potential emissions and air pollution.

Measure	CONSEQUENCE				Impact Probability	Overall Risk Level	Potential for Mitigation
	Impact Intensity	Impact Scale	Impact Duration	Summary			
Fire	M	M	L	M	H	Medium	Low
Biological Control							
Boer Goats	L	M	L	L	H	Medium	Low
Wild Browsers & Grazers	L	M	L	L	H	Medium	Low
Fungi	*Insufficient information available for an informed assessment in the Namibian context.*						
Insects							
Chemical Control							
Soil Applied Arboricides	L	L	L	L	L	Low	Low
Foliar Spraying	M	L	L	L	M	Medium	Medium
Stem Application	L	L	L	L	L	Low	Low
Manual Control	L	L	L	L	L	Low	Low
Mechanical Control							
Heavy Machinery	M	M	L	M	H	Medium	Low
Rolling	M	M	L	M	H	Medium	Low
Seeding & Inter-seeding							
Seeding	L+	L+	L+	L+	L+	Low+	n/a
Inter-Seeding	L+	L+	L+	L+	L+	Low+	n/a
Soil Enhancement							
Brush Packing	L+	L+	L+	L+	L+	Low+	n/a
Wood Ash	L	M	L	L	M	Medium	Medium
Wood Acid	L	L	L	L	L	Low	Low
Charcoal	L	L	L	L	L	Low	Low
Grazing Management	L	M	M	L	M	Medium	Low
Pruning	L	L	L	L	L	Low	Low

Water

Considers different components of the hydrological cycle and the water holding capacity of the soil and landscape.

Measure	CONSEQUENCE				Impact Probability	Overall Risk Level	Potential for Mitigation
	Impact Intensity	Impact Scale	Impact Duration	Summary			
Fire	L	M	L	L	M	Medium	Medium
Biological Control							
Boer Goats	L	L	M	L	M	Medium	Medium
Wild Browsers & Grazers	L	M	M	L	L	Low	Low
Fungi	*Insufficient information available for an informed assessment in the Namibian context.*						
Insects							
Chemical Control							
Soil Applied Arboricides	H	M	H	H	M	High	Medium
Foliar Spraying	L	M	M	L	M	Medium	Medium
Stem Application	L	L	M	L	M	Medium	Medium
Manual Control	L	L	M	L	M	Medium	Low
Mechanical Control							
Heavy Machinery	M	L	M	M	M	Medium	Low
Rolling	L	L	M	L	M	Medium	Low
Seeding & Inter-seeding							
Seeding	L+	L+	M+	L+	M+	Medium+	n/a
Inter-Seeding	L+	L+	M+	L+	M+	Medium+	n/a
Soil Enhancement							
Brush Packing	M+	L+	M+	M+	H+	Medium+	n/a
Wood Ash	L+	L+	M+	L+	L+	Low+	n/a
Wood Acid	L+	L+	M+	L+	L+	Low+	n/a
Charcoal	M+	L+	H+	M+	H+	Medium+	n/a
Grazing Management	L	M	H	M	H	Medium	Medium
Pruning	L+	L+	L+	L+	L+	Low+	n/a

Land

Considers primary productivity of the land, nutrient cycling, impacts on soil properties and conditions, erosion, surface temperature of the soil as well as the aesthetic appeal of the landscape.

Measure	CONSEQUENCE				Impact Probability	Overall Risk Level	Potential for Mitigation
	Impact Intensity	Impact Scale	Impact Duration	Summary			
Fire	L	L	L	L	L	Low	Low
Biological Control							
Boer Goats	L	L	M	L	L	Low	Low
Wild Browsers & Grazers	L	L	L	L	L	Low	Low
Fungi	*Insufficient information available for an informed assessment in the Namibian context.*						
Insects							
Chemical Control							
Soil Applied Arboricides	M	L	M	M	M	Medium	Medium
Foliar Spraying	L	L	L	L	L	Low	Low
Stem Application	L	L	L	L	L	Low	Low
Manual Control	L	L	L	L	L	Low	Low
Mechanical Control							
Heavy Machinery	H	L	H	H	M	High	Medium
Rolling	M	L	H	M	M	Medium	Medium
Seeding & Inter-seeding							
Seeding	L+	L+	M+	L+	M+	Medium+	n/a
Inter-Seeding	L+	L+	M+	L+	M+	Medium+	n/a
Soil Enhancement							
Brush Packing	L+	L+	M+	L+	H+	Medium+	n/a
Wood Ash	L+	L+	M+	L+	M+	Medium+	n/a
Wood Acid	L+	L+	M+	L+	M+	Medium+	n/a
Charcoal	M+	L+	H+	M+	M+	Medium+	n/a
Grazing Management	M	L	M	M	M	Medium	Medium
Pruning	L	L	L	L	L	Low	Low

Biota

Considers impacts on the habitat, biological diversity and species composition of flora and fauna, alien invasive species as well as food and feed availability.

Measure	CONSEQUENCE				Impact Probability	Overall Risk Level	Potential for Mitigation
	Impact Intensity	Impact Scale	Impact Duration	Summary			
Fire	M	L	L	L	M	Medium	Medium
Biological Control							
Boer Goats	M	L	M	M	M	Medium	Low
Wild Browsers & Grazers	L+	L+	L+	L+	L+	Low+	n/a
Fungi	*Insufficient information available for an informed assessment in the Namibian context.*						
Insects							
Chemical Control							
Soil Applied Arboricides	M	M	M	M	M	Medium	Medium
Foliar Spraying	M	L	L	L	M	Medium	Medium
Stem Application	L	L	L	L	L	Low	Low
Manual Control	L	L	L	L	L	Low	Low
Mechanical Control							
Heavy Machinery	H	L	M	M	H	Medium	Low
Rolling	H	L	M	M	H	Medium	Low
Seeding & Inter-seeding							
Seeding	M+	L+	M+	M+	M+	Medium+	n/a
Inter-Seeding	M+	L+	M+	M+	M+	Medium+	n/a
Soil Enhancement							
Brush Packing	M+	L+	M+	M+	M+	Medium+	n/a
Wood Ash	L+	L+	L+	L+	L+	Low+	n/a
Wood Acid	L+	L+	L+	L+	L+	Low+	n/a
Charcoal	M+	L+	H+	M+	M+	Medium+	n/a
Grazing Management	M	L	M	M	L	Low	Low
Pruning	L	L	L	L	L	Low	Low

Summary

Measure	Air	Water	Land	Biota	Overall
Fire	Medium	Medium	Low	Medium	Medium
Biological Control					
Boer Goats	Medium	Medium	Low	Medium	Medium
Wild Browsers & Grazers	Medium	Low	Low	Low+	Low
Chemical Control					
Soil Applied Arboricides	Low	High	Medium	Medium	Medium - High
Foliar Spraying	Medium	Medium	Low	Medium	Medium
Stem Application	Low	Medium	Low	Low	Low
Manual Control	Low	Medium	Low	Low	Low
Mechanical Control					
Heavy Machinery	Medium	Medium	High	Medium	Medium - High
Rolling	Medium	Medium	Medium	Medium	Medium
Seeding & Inter-seeding					
Seeding	Low+	Medium+	Medium+	Medium+	Medium+
Inter-Seeding	Low+	Medium+	Medium+	Medium+	Medium+
Soil Enhancement					
Brush Packing	Low+	Medium+	Medium+	Medium+	Medium+
Wood Ash	Medium	Low+	Medium+	Low+	Low+
Wood Acid	Low	Low+	Medium+	Low+	Low+
Charcoal	Low	Medium+	Medium+	Medium+	Medium+
Grazing Management	Medium	Medium	Medium	Low	Medium
Pruning	Low	Low+	Low	Low	Low

5. Conclusions

Currently, limited post-harvest treatments are conducted in Namibia due to the costs involved and a lack of knowledge, understanding and interest (Pers. Comm. Peter Cunningham, Axel Rothauge). However, post-harvest treatments are necessary to justify the initial investment into bush control to restore landscapes (Pers. Comm. Progress Kashandula) and control bush regrowth. It must be a continuous process to avoid regrowth and other problem plants from emerging (Pers. Comm. Michael Dege).

Post-harvest treatment is heavily dependent on the method used for the initial control or harvesting, the size of the area and the tree species to be controlled (Pers. Comm. Peter Cunningham). Encroacher species have different traits that affect the effort required to control regrowth and recruitment. Especially harvested areas where *Dichrostachys cinerea* (sickle bush) was dominant before control/harvesting may be difficult to control (De Wet 2015; SAIEA 2016; Pallett & Tarr 2017; Pers. Comm. Ben Strohbach) and should be properly planned for in advance. Traits that make *D. cinerea* control challenging include the ability to rapidly regrow from disturbed roots (De Wet 2015) and stems (Joubert 2014), the persistent and long-lived seed bank of this species and effective dispersal of seeds by animals (Joubert 2014). *D. cinerea* also tend to be more resistant to soil-applied arboricides than other encroacher species, requiring a higher dose to control (De Klerk 2004). Fortunately, *D. cinerea* is sensitive to current stem and foliar-applied arboricides. For sicklebush, fire tends to facilitate seedling establishment and chemical control may be the only option, although Zapke (1986) indicated that goats could control sicklebush at moderate densities. Other species can be well controlled with other measures: *Vachellia luederitzii* can be easily controlled with stem burning; Mopane is very suitable for pruning and sustainable harvesting operations removing only certain branches (Pers. Comm. Michael Dege) and *Senegalia mellifera* seedlings are effectively controlled with fire (Joubert et al. 2012).

Also, the geographical conditions, bush density and the main farming system should provide the basis for a detailed analysis of the site conditions (Pers. Comm. Progress Kashandula). The success and methods to be used for post-harvest treatments also depend on the biome and the initial harvesting method (Pers. Comm. Stephan Bezuidenhout). An important indicator is the nutrient status of the soil: An imbalance between anabolic (e.g. Mn, Mg) and catabolic (e.g. Cu, Zn) minerals can be a cause for bush thickening (Pers. Comm. Ibo Zimmermann; Mills et al. 2017).

A key consideration is the desired state of the landscape. According to some interview partners, Namibia does not naturally have grasslands. An overemphasis on creating grassland instead of a mosaic savanna with thickets of bush can encourage higher stocking rates, overgrazing and favour further bush thickening (Pers. Comm. Peter Cunningham). Early explorers reported dense patches of bush in some areas (Cunningham 2014), which suggests that bush thickening is a natural phenomenon and part of the savanna ecosystem and Namibia's landscape.

Especially large trees contribute to the stability of savanna ecosystems leading to local soil enrichment underneath canopies and the suppression of 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 under large trees also increase the available nutrients for plants. The removal of large trees changes the structural diversity of the landscape and can negatively impact species diversity (Tews et al. 2004). Selective thinning allowing a good, uniform stand of large trees and bushes to help suppress the growth of young woody plants, as well as suppressing the establishment of recruits close to large trees and bushes is advocated to reduce the post-harvest effort

(Smit et al. 2015). Key considerations in bush control should also be to create a mosaic and avoiding sensitive areas and micro-habitats (Pers. Comm. Peter Cunningham). This can support post-harvest treatment success.

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 may require continuous efforts to avoid encroacher species to (re)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).

Secondly, the competitiveness of the herbaceous layer should be encouraged through an effective grazing management system aiming to increase the vigour and competitiveness of perennial grasses (Smit et al. 2015). Managing for a competitive herbaceous layer may take several seasons and will depend on the level of degradation (e.g. perennial grass cover loss), as well as current climatic conditions. Even in the best of cases will these actions not be enough to maintain an open savanna state indefinitely but will result in both fewer woody recruits to be dealt with and will reduce the growth rate of surviving plants in the post-harvest programme (Smit et al. 2015). The use of by-products of bush harvesting such as brush packing, spreading ash and wood acids, as well as reseeding with indigenous grass seeds are intended to treat degraded areas or to accelerate restoration efforts. The positive impacts of these efforts may be small initially but long-lasting or self-reinforcing over time.

Thirdly, the season when harvesting, and by inference therefore also post-harvest measures, are employed appears to affect the subsequent growth and mortality rate of cut woody plants. Strohbach (1998/1999) found that cutting Namibian encroacher species during the rainy season (i.e. January to April) significantly decreased coppice growth and survival rates of five encroacher species, although the survival rate of *Dichrostachys cinerea* and *Terminalia sericea* remained high in this experiment, even in the second year of the trial (Strohbach 1998/1999). The factors mentioned above may slow down the re-infestation rate of the harvested areas but does not negate the necessity of controlling coppice growth and reproducing woody plants years after the initial harvest event.

It was also suggested that aftercare is not enough. The land should be prepared before bush control and the main causes of bush thickening must be identified. There is a general need for a more holistic approach considering all stages and long-term ecological impacts (Pers. Comm. Ibo Zimmermann). The pre-treatment of land can have positive effects: For example, high-density grazing before harvesting for charcoal can take off the leaves, loosen the soil through trampling and deposit manure on-site improving soil fertility (Pers. Comm. Michael Dege).

Some new methods are being trialled in Namibia, for example using frontend loaders with wheels covered in chains to minimise punctures. The tracks with chains reduce soil compaction and mimic large herds of herbivores trampling an area (Pers. Comm. Stephan Bezuidenhout). There is considerable controversy around the use of fire. While ecologist believes it is the best and most natural way to conduct post-harvest control, farmers or rangeland scientists are more sceptical.

Within the FSC guidelines, chemicals are considered the last resort and a good justification is required to use chemicals. Picloram a widely recommended chemical in Namibia is on the FSC List of Highly Hazardous Pesticides (Pers. Comm. Stephan Bezuidenhout).

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8. Annex

Evaluation Criteria for Risk Assessment

PART B: DETERMINING CONSEQUENCE					
		SEVERITY = L			
DURATION	Long term	**H**	Medium	Medium	Medium
	Medium term	**M**	Low	Low	Medium
	Short term	**L**	Low	Low	Medium
		SEVERITY = M			
DURATION	Long term	**H**	Medium	High	High
	Medium term	**M**	Medium	Medium	High
	Short term	**L**	Low	Medium	Medium
		SEVERITY = H			
DURATION	Long term	**H**	High	High	High
	Medium term	**M**	Medium	Medium	High
	Short term	**L**	Medium	Medium	High
			L	**M**	**H**
			Localised Within site boundary **Site**	**Fairly widespread** Beyond site boundary **Local**	**Widespread** Far beyond site boundary **Regional/ national**
			SPATIAL SCALE		

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	Medium	Medium	High
	Possible/ frequent	**M**	Medium	Medium	High
	Unlikely/ seldom	**L**	Low	Low	Medium
			L	**M**	**H**
			CONSEQUENCE		