Final Report

Baseline Study of Bush Encroachment and Available Management options for the Windhoek Green Belt Landscape

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for

Ministry of Environment and Tourism
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Through NAMPLACE Project

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Summary

This final report is a requirement of the Terms of Reference for a short-term consultancy to undertake a Baseline Study on Bush Encroachment and Available Management options for the Windhoek Green Belt Landscape (WGBL). The report aims to inform stakeholders within WGBL of the available management interventions to combat bush encroachment and monitor progress.

Although emphasis should be placed on the prevention of bush encroachment by treating the root causes, the fact that mature bushes have already encroached on many parts of the WGBL means that these symptoms also need to be treated. Various options for controlling encroached bushes are evaluated by discussing both their positive and negative attributes, suggesting mitigation measures against negative attributes and providing recommendations. The main options considered are the timely application of veld fire, selective stem burning, manual chopping of selected encroached bushes, aerial application of soil-based arboricide and selective manual application of soil-based arboricide. Tebuthiuron is viewed as the most appropriate soil-based arboricide, applied as granules near the base of the target bushes at the start of the rainy season. However, *Laggera decurrens* is not controlled by Tebuthiuron, and *Dichrostachys cinerea* requires a higher dosage applied directly at the base of its main stem. An innovative tool, the Tree Popper, is also recommended for levering out small saplings

Principles to consider when controlling encroached bushes include the avoidance of arboricides if other options are available, the protection of large trees with widespread roots that prevent smaller bushes from growing bigger, and retention of some patches of dense bush to improve biodiversity. In most cases it will be necessary to apply follow-up treatment a few years after the initial control, which often weakens bushes temporarily and/or favours invasion by new bushes. Relevant principles include the use of adaptive management that makes use of opportunities when conditions favour a particular method of control or when invading bushes reach a weak point, and the application of preventative management largely though controlled grazing that maintains the competitive advantage of perennial grasses.

Monitoring is necessary to identify needs and opportunities for timely application of adaptive management, and to determine the level of success of previously applied management. To allow differentiation between changes caused by fluctuating rainfall and changes resulting from bush control, it is useful to compare changes at sites targeted for bush control with changes at reference sites where bushes will not be controlled. Fixed-point photographs provide a visual impression of changes at particular sites. Farmers are encouraged to continue to take photographs from both target sites and reference sites marked with steel Y-posts at the five farms surveyed. The surveys sampled bushes shorter and taller than 1m and perennial grasses, both at the target and reference sites. Results from the target sites, and type of recommended bush control, appear in the summary table on the following page.

Summary table of monitoring results and recommended type of bush control for target area on each of the five farms surveyed in the Windhoek Green Belt Landscape

Farm	**Düsternbrook**	**Monte Christo**	**Ombuenja**	**Otjisewa**	**Onduno**
Density of bushes >1m tall per ha	496	1075	1120	812	465
Main species >1m tall	*Dichrostachys cineria*	*Acacia erubescens*	*Acacia mellifera*	*Laggera decurrens*	*Dichrostachys cineria*
Density of bushes <1m tall per ha	553	1337	2337	1307	1194
Main species <1m tall	*Acacia erubescens*	*Laggera decurrens*	*Laggera decurrens*	*Catophractes alexandrii*	*Catophractes alexandrii*
Density of perennial grasses per ha	720	1200 (Excluding *M. Caffra*)*	9970	3928	91136 (but 59238 if *M. Caffra* is excluded)*
Main perennial grass species	*Stipagrostis uniplumis*	*Eragrostis lehmanniana**	*Cenchrus ciliaris*	*Eragrostis tricophora*	*Microchloa caffra**
Mean height of tallest bush or tree per 314m^2	3.9m	4.9m	7.2m	1.5m	4.3m
Main tallest species	*Dichrostachys cineria*	*Acacia erubescens*	*Acacia karroo*	*Laggera decurrens*	*Dichrostachys cineria*
Recommended bush control in target area	Apply veld fire, only when fuel is sufficient	Apply veld fire, only when fuel is sufficient	Manually clear target species in the small target area; use the Tree Popper for the *Acacia mellifera* saplings	Apply Tebuthiuron granules at base of target species <1m or use the Tree Popper	Apply Tebuthiuron granules at base of target species <1m or use the Tree Popper

* *Microchloa caffra* was excluded from the survey at Monte Christo, where its tiny size was considered to contribute insignificantly to fuel and forage, but it was included in the survey at Onduno

1. <u>Introduction</u>

1.1 Background

This final report is a requirement of the Terms of Reference for a short-term consultancy to undertake a Baseline Study on Bush Encroachment and Available Management options for the Windhoek Green Belt Landscape (WGBL). The report aims to inform stakeholders within WGBL of the available management interventions to combat bush encroachment and monitor progress. This short-term consultancy was commissioned by the Namibian Protected Landscape Conservation Areas Initiative (NAM-PLACE), a project of the Ministry of Environment and Tourism (MET) through the Directorate of Environmental Affairs, with co-financing from the Global Environment Facility (GEF) though United Nations Development Programme (UNDP).

1.2 Encroacher species

Although scientific names are universal, they are not well known by everybody. Therefore Table 1 below lists the encroaching bush species by scientific name together with some local names, to improve communication about the species.

Table 1. Encroacher bush species of the Windhoek Green Belt in various languages

Scientific name	**Afrikaans name**	**Otjiherero name**	**English or German name**
Acacia erubescens	Withaak	Omungongomwi	Yellow-bark Acacia
Acacia karroo	Soetdoring	Erusu	Weissdorn
Acacia mellifera	Swarthaak	Omusaona	Black-thorn Acacia
Acacia reficiens	Rooihaak	Omungondo	Rotrindenakazie
Acacia tortilis	Haak-en-steek	Orusu	Umbrella thorn
Catophractes alexandrii	Ghabbabos	Omukaravethi	Trumpet-thorn
Dichrostachys cineria	Sekelbos	Omutjete	Kalahari Christmas tree
*Laggera decurrens**	Bitterbos	Omutumba	Bitter bush
Lycium bosciifolium	Brosdoring	Okahua	Bocksdorn
*Petalidium engleranum**	Voerbos		
Protasparagus spp.*	Katdoring		Asparagus

***** These species are not strictly bushes, but rather forbs or dwarf shrubs

2. <u>Recommendations of sustainable and environmentally friendly methods of controlling the problem suitable for the area</u>

2.1 Symptom Treatment

Ideally, management that prevents bushes from encroaching should be the norm. However, bush encroachment, for reasons of history, is already a problem (Rhode & Hoffmann, 2011) and thus symptom treatment is necessary. If applied alone, without applying preventative management, its efforts will be wasted as the causes will still be present and conditions will favour re-invasion of bushes. Therefore preventative management should also be applied and it is addressed later in this report.

In the Decision Support System that we have developed for the Highland Savanna (Joubert et al., 2010), we have approached symptom treatment in a fairly general way, not going into particular detail. However, it was mainly focussed on *Acacia mellifera* control. *A. mellifera* did not form a large proportion of the problem on the surveyed farms, but, with some precautions, symptom treatment for all "problem" species should be similar. The tables presented below provide an overview. Honsbein et al. (2009) presented a cost benefit analysis (CBA) of different methods of symptom treatment, from the economic, social and ecological sustainability perspective. These were summarised in a series of tables which are presented below in an adapted form.

Table 2. Positive and negative attributes of fire as a means of bush control

	Economic	**Ecological**	**Social**
Positive	Desirable fodder trees bud very early after fire is applied, supplying browse (economic positive also).		If farmers coordinate their fire management such as in some areas of South Africa and Australia, this could enhance cooperation
	High quality grass the next season can reduce lick costs by half	Mineralisation is rapid and available for grass growth, grass is more nutritious	
	Large areas can be cleared rapidly at very little expense	Patches of burnt and unburnt areas increases biodiversity	
		Small problematic saplings and seedlings are likely to be destroyed	
Negative	The rapid regrowth of woody species after fire from woody resprouts reduces the gains in grass production	Runaway fires can have adverse effects on biodiversity in the short term	Limited employment opportunities
		Fires applied incorrectly can cause more shrub encroachment(fires too cool for example)	Runaway fires can cause losses on neighbouring farms resulting in ill feeling and law suits etc.
		Fire removes organic material	Health risks if fire is not well controlled
Mitigations & Recommendations	Goats, or browsing game, can consume resprouting *Dichrostachys cinerea*, and thus control its regrowth*		Firebreaks need to be effective, and the fire needs careful planning and control, training in fire management should be considered
	Firebreaks can be made through grazing by livestock to offset opportunity costs	Fire should be applied only in dry seasons after exceptional rainfall years to ensure that grass production and health is not negatively affected.	
	Fire treatment, followed by arboricide treatment can be applied (1/3 the normal amount of arboricide), thus reducing costs if used as a symptom treatment	Livestock can be used to protect large trees by allowing them to graze the nutritious grasses around the trees before the fire	Neighbours need to be informed and involved

* It is important that animals come to feed on resprouting shoots after the fire, not only for weakening encroached bushes but also to provide a trampling and fertilizing service, otherwise the soil will become capped and grasses will lose vigour. The animals will benefit from the nutritious shoots, but it is recommended that they also have access to unburnt grass to avoid diarrhoea from sudden change in diet. Rest may then be provided for grasses during the following growing season.

namibia landscape conservation

Table 3: Positive and negative attributes of manual cutting (chopping)* as a means of bush control

	Economic	**Ecological**	**Social**
Positive	Can be used as the basis for charcoal production or other utilisation of wood. Charcoal can be utilised more than once from the same area after 15 to 20 years. NPV positive if off farm sale of bush / charcoal	Resprout can be consumed by browsers, including browsing game. Chopped branches can be used for erosion control or temporarily protecting desirable bushes and trees from browsers.	Large opportunities for employment, both with clearing as well as charcoal production
Negative	Grass production does not increase as much as with other clearing methods, since regrowth of wood is rapid	Rapid regrowth often results in a worse bush encroachment situation	A number of social problems reduce the popularity of this amongst farmers
	If regrowth is not wanted, the application of an arboricide such as Access is needed	If the wood is removed, nutrients are lost from the system	Large numbers of contracted workers often result in unwanted fires, increased exposure of permanent workers to HIV infection, poaching and other social problems
Mitigations & Recommendations	Regrowth can be pruned to reduce the number of stems but increase their size Goats, or browsing game, can consume resprouts and therefore contribute to revenue	Cutting in autumn before photosynthates are translocated to the roots needs further investigation (De Klerk, 2004) Plants can be chopped beneath the surface to a depth of 10 cm (De Klerk, 2004) Nutrients, in the form of ash should be returned, if charcoal is produced	Contractors should be well trained, and have well trained Natural Resource Managers in the teams. Teams should have constant supervision

***** Mechanical methods such as bulldozer, rotary and chain saws are considered to be not economically viable due to high costs of purchase, operation and maintenance. The best axe for felling Namibian bush is considered by Consulting Services Africa (2007) to be the Elwel 4lb.

Table 4: Positive and negative attributes of the aerial application of soil based arboricides, followed by two after care hand applications

	Economic	Ecological	Social
Positive	Large areas cleared rapidly	If trees remain, act as island nurseries for valuable fodder species	Less poaching and other labour problems minimised
	Very rapid increase in overall production	If applied to dense monostands, can be viewed as a rapid reversion to “original” open grassy state	
Negative	NPV negative if not followed by manual harvest & off farm sale of bush / wood	Landscape scale change in habitat	Little job creation
	Expensive treatment, and cannot get FSC certification for charcoal, thus fetches a lower price	Secondary invasions of e.g. *Lagerra decurrens* are encouraged	
	Not effective against *D. cinerea* and in clays of > 20 %	Unknown subtle ecosystem impacts are possible but not researched yet	
	At least 2 follow up applications are necessary	Structural and species diversity is reduced	
	Non selective: fodder and other trees can be adversely affected		
Mitigations & Recommendations	Using it in combination with fire will reduce costs	If possible, leave dead trees in situ	
	Use only for very dense monocultures of species such as *A. mellifera*	Conduct research	
	Ensure that follow up treatments (applied by hand) are done soon enough to ensure that regrowth has not recovered sufficiently		

Table 5: Positive and negative attributes of the selective hand application of soil-based arboricides*, followed by two after care hand applications

	Economic	Ecological	Social
Positive	Large areas cleared fairly rapidly	If trees remain, act as island nurseries for valuable fodder species	Job creation opportunities are flexible and can be increased
	Very rapid increase in overall production	Selectivity means a landscape of patches and open areas can be created	Treatment can be incorporated into farming programme
	NPV negative if not followed by manual harvest and off farm sale of bush / wood	Fodder trees can be mostly avoided	
	Considered to be most cost effective method generally	Small problematic saplings can be targeted	
Negative	Fairly expensive treatment/ ha	Landscape scale change in habitat (if non selectively applied)	
	Overapplication is possible, increasing expenses	Overapplication is possible, increasing non target mortalities	
		Unknown subtle ecosystem impacts exacerbated by overapplication are possible but not researched	
	Charcoal cannot be FSC certified, and thus will fetch a lower price		
Mitigations & Recommendations	Thin to recommended levels		Job creation opportunities can be maximised
	Only use to recommended levels per hectare		
	Ensure that follow up treatments are done soon enough to ensure that range can be managed to maintain its openness in the future		
	Use in combination with fire treatments to reduce costs	If possible, leave dead trees *in situ*	
		Thin to recommended levels, leave patches	

*The two most common types of soil based arboricide readily available in Namibia are Bromacil and Tebuthiuron (Honsbein et al., 2012), which are often sold in combination. Based upon the experiences of Prof. Nico Smit in South Africa, Tebuthiuron is the safest of the two because Bromacil tends to move laterally in the soil and harm non-target bushes and trees. However, *Laggera decurrens* is not controlled by Tebuthiuron, but by the more expensive Triclopyr and Picloram.

Table 6: Positive and negative attributes of stem burning

	ECONOMIC	ECOLOGICAL	SOCIAL
Positive	No loan required from bank (unless large teams of workers are employed)	If trees remain, act as island nurseries for valuable fodder species	Treatment can be incorporated into farming programme
	In communal situations, no measurable expenses are incurred if the community works together to do the stem burning	Selectivity means a landscape of patches of thickets and open areas can be created	Job creation opportunities are flexible
	NPVs negative if not accompanied by manual harvest and off farm sale of bush / wood	Valuable fodder and other non encroaching trees can be avoided	
		Dung used for fuel increase fertility of soil	
		Decomposition of standing trees might be more rapid than in the case of arboricides	
Negative	Clearing is slow, thus slow increase in overall production	Small areas cleared can be immediately overgrazed by game, selecting nutritious grasses	
Mitigations & Recommendations	Produce charcoal or electricity	Clear larger areas to avoid overgrazing by game	Can increase the number of people in teams (costly but will increase production more rapidly to offset the costs)

For more details, refer to Honsbein et al. (2009).

Some important principles that should be considered, regarding treatment of the symptoms, are given below:

Principle 1: Minimise the use of arboricides if other approaches are available
The ecological impacts of arboricides are not well understood or documented. A comprehensive literature review (Honsbein et al., 2012) deals with some of the processes and impacts on soils and ground water, but these have not been measured in Namibia, in relation to the current use of arboricides, through aerial and / or hand application.

Principle 2: Keep larger trees
The removal of large trees often results in the release of saplings from competition, resulting in rapid growth and an exacerbation of the situation. It is thus very important to leave a number of large trees of the encroaching species, despite the economical attractiveness of harvesting them.

Principle 3: Do not regard the bush as an enemy
Maintain some patches of thickets, which increase biodiversity as they create a habitat for certain species which prefer thickets, and increase the habitat diversity for species that require both thickets and open savannas.

2.2 Post symptom treatment

There are some general principles to be followed, and management practices that should be carried out once the symptoms have been treated (bush encroached areas have been thinned out, resulting in reduced densities and cover). If initial treatment only achieved top-kill of bushes, then the resprouts could grow rapidly from the roots, in which case a follow-up treatment will be needed within two or three years to weaken the roots. If initial treatment killed bushes outright, then seedlings are more likely to establish and saplings are more likely to grow rapidly since their suppression by larger bushes will have been removed. In this case a follow-up treatment will be needed to control seedlings and saplings. The general principles are explained below.

The first important principle is that adaptive management should be followed. Most importantly, following from this principle, extreme natural events (high rainfall; drought; frost; fire) can be used to the farmer's advantage in conjunction with other factors (browsing for example).

Principle 1: Apply adaptive management
High Rainfall (followed by fire)
Protracted periods of consecutive years of high rainfall result in the *en masse* production of *Acacia mellifera* seeds (1st consecutive year of very high rainfall); germination of seeds and survival of seedlings (2nd consecutive year of high rainfall) and establishment of seedlings (3rd consecutive year of high rainfall), hence a potential establishment period. During these three years then, a potential hazard occurs. However, the high rainfall also presents an opportunity for the farmer: high fuel loads for hot fires. In the first year, fires set during the fruiting of *Acacia mellifera* will arrest the development of the fruits, thus preventing seeds from being dispersed. However, this approach probably only applies to *A. mellifera* and the phenologies of other encroaching species will have to be investigated. In the second year, fires will cause an almost 100 % mortality of seedlings, as will fire in the third year. This probably holds true for all encroaching species. In other species, with more persistent seed banks, such as *A. reficiens* and *D. cinerea*, seeds may germinate and survive in the first high rainfall year, thus a fire in this year should kill seedlings. Importantly, farmers should monitor in order to determine whether the hazard (seeds, seedlings) is present. This should also be done per camp, or in the case of unfenced areas, per area, and priority should be given to areas adjacent to encroached areas. Firebreaks can then be constructed to ensure that only

areas where the hazard is present are burnt, and also to ensure that there is sufficient reserve grazing, in particular if the follow up rains are poor.

In general then, rainfall provides a hazard (woody seedling establishment) but also an opportunity (hot fires based on high fuel loads) to kill these very seedlings. Currently we feel that if fires do not occur during these establishment phases then saplings will be present and will generally survive fires thereafter to form bush thickets. This is then ***preventative*** adaptive management. However, fires can be also used in other adaptive ways in conjunction with other disturbances.

Drought (possibly followed by fire)
A. mellifera is surprisingly prone to die-back in drought years, especially in conjunction with fungal dieback, a disease prevalent in Namibia and responsible for the opening up of large areas through the dieback of *A. mellifera*. Some farmers have observed that the trees resprout once good rains occur. Thus either the drought and fungal dieback can be regarded as a cheap means of bush control, whereby the farmer can then focus on other areas where trees have not died back or, in addition, the farmer can use this dieback as a preparation for when fires do occur (after good rains and a fuel load build up). This is explained in detail in the next section. However, *A. mellifera* was not common in areas to be targeted.

Frost (followed by fire)
Recent extreme cold events (2011) around Windhoek and other areas resulted in the die back of a number of *A. mellifera*s. These trees and saplings resprouted but the regrowth is very slow. This provides an ideal opportunity for a manager to use fire in the following season, provided there is sufficient fuel load to carry the fire. The tree skeletons, after a year, will hold very little moisture, and are likely to burn (also the case with drought dieback). Once they do, the weak resprout is likely to be killed outright, given the long duration of the fire, as the skeleton continues to burn long after the grass fire has moved on.

Principle 2: Apply sound rangeland management options to prevent further encroachment
Once areas have been opened up, and the use of fire in adaptive situations is considered, other sound management approaches will prevent, or minimise the chances of re-encroachment occurring.

2.3 Preventative management

For background analysis of the causal linkages of bush encroachment it may be useful to read the article in Appendix 1. A characteristic of healthy rangeland that prevents bush encroachment is a good cover of perennial grasses in balance with scattered trees that outcompete bush seedlings and saplings. Perennial grass is kept vigorous by being grazed, to prevent it accumulating old leaves and becoming moribund, followed by long rest in the growing season to replenish root reserves that were borrowed to produce new shoots after grazing. Herds of wild animals used to migrate seasonally and provide perennial grasses with this invigorating grazing followed by rest, but boreholes and fences have put a stop to that. One of the consequences is weakening of perennial grasses, either by continuous grazing such as near water supplies, or by undergrazing such as far from water, followed by bush encroachment. The weak grass fails to compete well enough with young bushes and fails to support an occasional lightning fire that is intense enough to weaken bushes.

Preventative management therefore consists largely of appropriate grazing management to keep perennial grasses vigorous, avoiding the removal of large trees that suppress small bushes, and applying occasional fire that weakens established bushes. To prevent fires from harming the large trees, grazing herbivores can be used strategically for creating firebreaks around their trunks. When released into a new area in the dry season, grazers tend to initially move from tree to tree, since the most nutritious grasses usually grow under their canopies. At a low stocking rate the grazers tend to graze down the grasses under tree canopies while leaving sufficient fuel for an intense fire over the majority of the rangeland.

Grazing management largely involves balancing the different types of browsing and grazing species to set their overall stocking rate, and controlling their movements. The movements of domestic animals are usually controlled by fencing. For game animals, a combination of push and pull methods is usually more effective. Options that attract animals away from areas needing rest, include the following:

- Opening of water points.
- Provision of supplementary lick or salt blocks.
- Burning, that attracts animals to graze on resprouting shoots.
- Previous grazing by bulk browsers such as cattle, to attract selective grazers to shorter grass.
- Spraying of dilute molasses onto grass, to make it more attractive for grazers.

Options that push game animals off areas needing rest, include:

- Temporary closing of water points and removal of supplementary lick or salt blocks.
- Disturbance such as human activity, especially if dogs are also present.
- Disturbing sounds, such as gun shots.
- Placement of cut thorn bushes, either over small patches of grass or as bush fencing to surround a larger patch.

The occurrence of year round semi-purified water in the river flowing through the Windhoek Greenbelt makes it difficult to provide rest in its vicinity. Dams constructed along seasonal rivers could be fenced off from access to most game species, when the surrounding rangeland is in need of rest.

Salt blocks are often placed at water points. This is rather wasteful in terms of controlling game movements, since animals are in any case attracted to the water. Their placement in less used parts of the rangeland could help to shift animal pressure, which can be alternated from time to time.

Fire has a large influence on animal movements and thereby also influences areas likely to get burnt in subsequent years. The grazing of regrowth after a fire usually results in insufficient fuel during the following season. If lightning were to strike there, it would unlikely burn due to shortage of fuel. Only areas that were unburnt the previous season are likely to burn in the following season and they would then attract the game animals there and away from the previously burnt area. However, not all years are suitable for the application of fire. After a poor rainy season there may be insufficient fuel as well as insufficient soil moisture in case of poor rains in the subsequent season.

3. Monitoring

Monitoring is necessary to identify needs and opportunities for timely application of adaptive management, and to determine the level of success of previously applied management.

Fixed-point photographs provide a visual impression of changes at particular sites. It is useful to compare changes at sites targeted for bush control with changes at reference sites where bushes will not be controlled. This will allow differentiation between changes caused by fluctuating rainfall and changes resulting from bush control. Farmers are encouraged to continue to take photographs from both target sites and reference sites marked with steel Y-posts at the five farms surveyed. The coordinates for these posts appear in Table 7 below.

Table 7. Coordinates of steel Y-posts that mark positions from where fixed point photos were taken.

Site	Coordinates South	Coordinates East
Düsternbrook Reference	22° 13.001'S	16° 52.855'E
Düsternbrook Target	22° 13.227'S	16° 52.764'E
Düsternbrook Saddle	22° 13.242'S	16° 54.037'E
Monte Christo Reference	22° 22.794'S	17° 01.309'E
Monte Christo Target	22° 22.263'S	17° 01.554'E
Ombuenja Reference	22° 18.577'S	16° 51.450'E
Ombuenja Target	22° 18.661'S	16° 51.547'E
Otjisewa Reference	22°18.376'S	16°57.354'E
Otjisewa Target	22°18.376'S	16°57.401'E
Onduno Reference	22°24.108'S	16°49.921'E
Onduno Target	22°24.108'S	16°49.921'E

A bush survey was undertaken within belts of 200m x 80m, using an adapted version of the method of Trollope (2011). A steel Y-post was placed at the start and end of the transect running through the middle of this belt. The fixed-point photos were taken from the start posts. At right angles to the transect and 20m on each side of the post, small beacons were constructed with stones to mark the start and end of transects along which measurements were taken at points spaced 40m apart. A cross was placed at each point and within each quarter the following were measured:

- The nearest bush shorter than 1m height, of which the species was recorded and its distance from the point and height measured.
- The nearest bush taller than 1m height, of which the species was recorded and its distance from the point and height measured.
- The tallest bush or tree within 20m of the point, of which the species was recorded and its height measured.
- The nearest perennial grass, of which the species was recorded and its widest basal diameter measured.

Measurements were taken in each quarter from 10 points, five along each transect, thereby sampling 40 of each of the categories of plants mentioned above. The data were entered into an Excel workbook and formulae and pivot tables were used to estimate the density of each plant category, the species composition and mean height, which were plotted on charts.

Figure 1 contains densities of the two height classes of bushes at each site, subdivided into three categories of species. *Laggera decurrens* was placed into a category of its own, because of its abundance at some sites and lack of control by cheaper arboricide. The other species were subjectively divided into encroacher species (Table 1) and non-encroacher species that included *Albizia anthelmintica, Acacia erioloba, A. hereroensis, Boscia albitrunca, Combretum apiculatum, Commiphora africana, Ehretia rigida, Grewia flava, G. flavescens, Searsia marlothii and Ziziphus mucronata*.

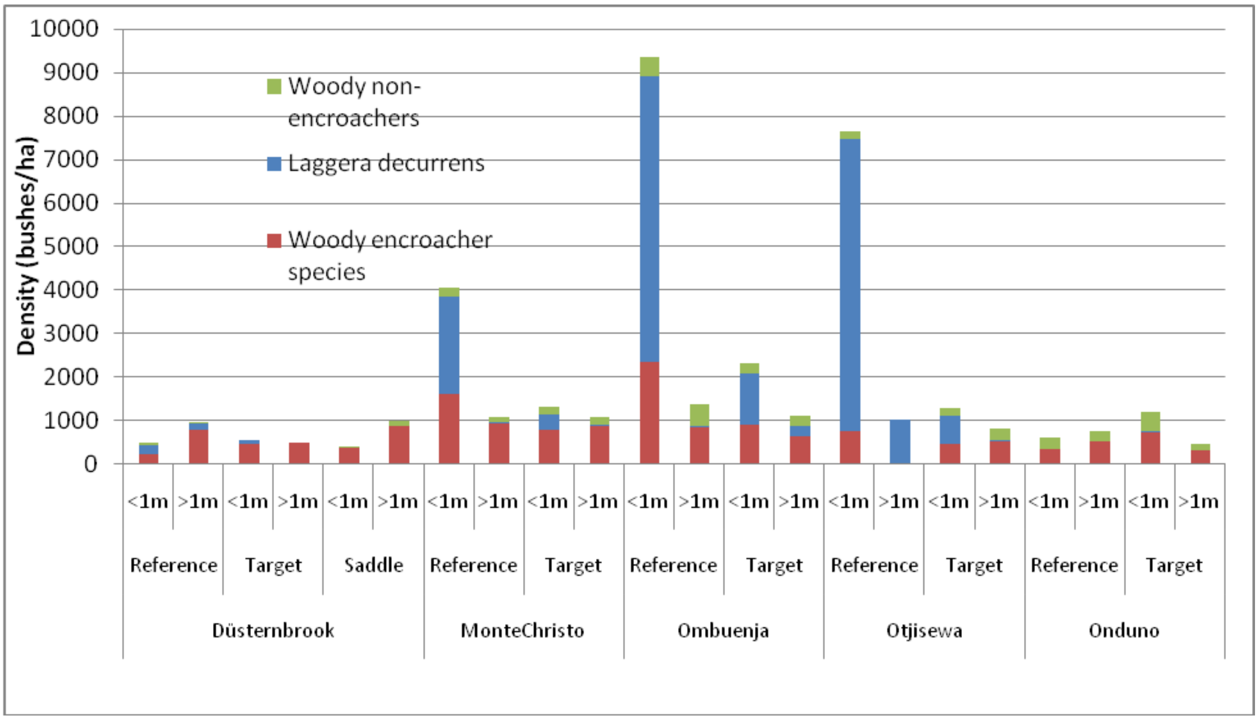

Figure 1. Densities of woody plants taller and shorter than 1m at each of the surveyed sites, divided into three categories of species.

According to the rule of thumb mentioned by de Klerk (2004), the number of tree equivalents per hectare should not exceed twice the long-term average annual rainfall (mm), where a tree equivalent (TE) is defined as a bush of 1.5m height. Taking a mean annual rainfall in the Windhoek Greenbelt of 350mm, this would imply a target of 700 TE/ha. Target sites on all five farms exceed that, even if *L. decurrens* is excluded from the density.

4. <u>Specific recommendations for areas targeted for treatment on the surveyed farms</u>

4.1 Düsternbrook
Description of sites including areas targeted for bush control:

		
Photo 1. Fixed point photo at reference site on Farm Düsternbrook	**Photo 2. Fixed point photo at lower site targeted for bush control on Farm Düsternbrook**	**Photo 3. Fixed point photo at upper site targeted for bush control at saddle on Farm Düsternbrook**

The sites are continuously grazed by a variety of game animals stocked at roughly 24 kg liveweight / ha. The reference site appeared to be more heavily grazed, probably due to the previous year's fire there.

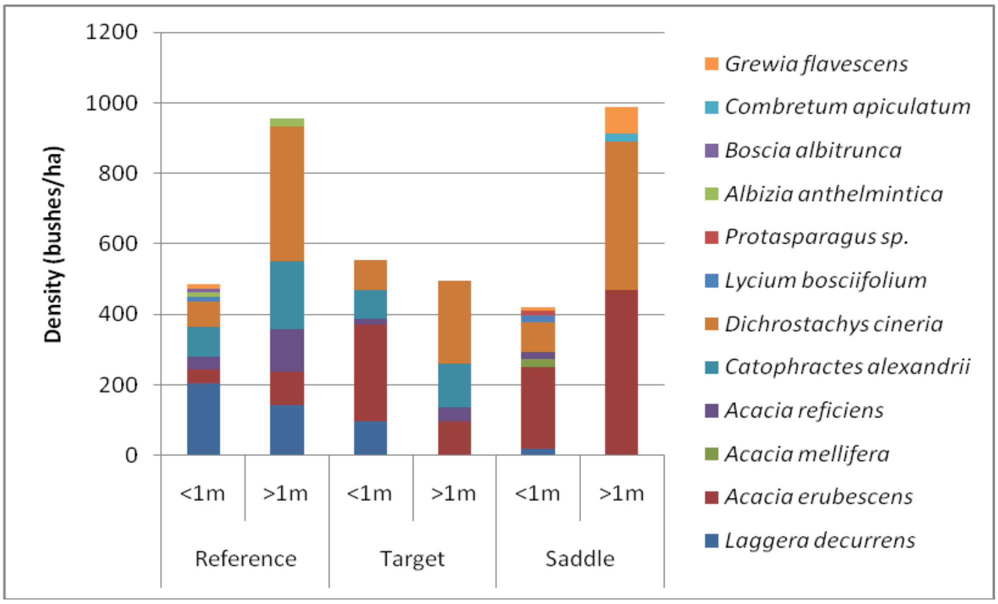

Figure 2. Bush densities at the three sites measured at Farm Düsternbrook, divided into species, with encroacher species on the bottom.

Figure 2 shows that *Dichrostachys cinerea* is dominant in the target area, for trees > 1m, followed by *Catophractes alexandrii*. The other target area, higher up the landscape at the saddle, has more *Acacia erubescens*. Height classes were similar at all three sites, with mean heights of bushes taller than 1m between 2m and 3m, and tallest trees at around 4m.

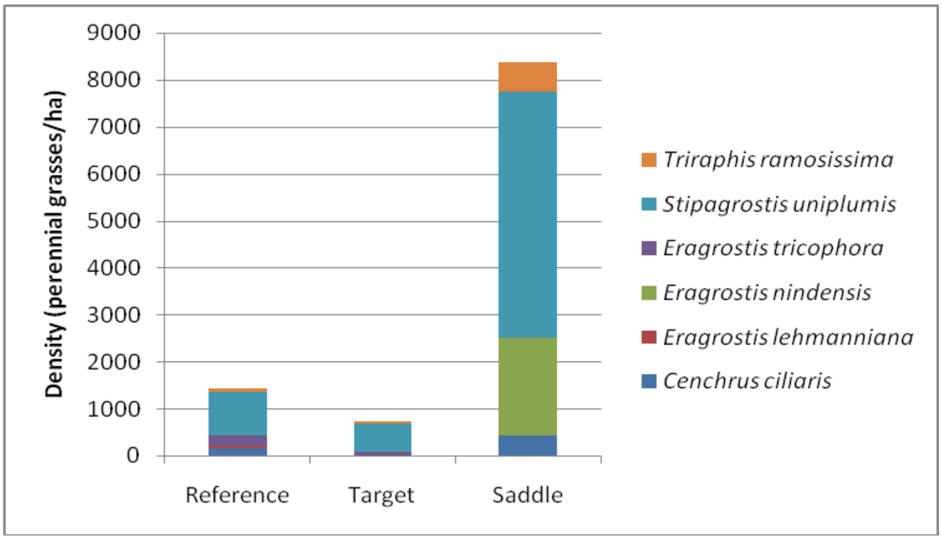

Figure 3. Densities of perennial grass at the three sites measured at Farm Düsternbrook, divided into species.

Figure 3 shows a low density of perennial grasses, especially at the lower target site. Although the grass density was much higher at the saddle, it was still rather low at less than one grass per m^2. The dominant species at all sites was *Stipagrostis uniplumis*. Annual grasses make up most of the fuel. The reference site had been burnt in 2011.

Farmer's method:
Mr. Vaatz intends to burn areas with a relatively high cover of woody species, followed perhaps 2 or 3 years later by another fire. If the bush density and cover is too high, and grass is insufficient for fire, he is prepared to either chop trees down, or hand apply soil based arboridices.

Our suggestions:
Tables 2, 4 and 5 summarise the advantages and disadvantages of the different methods. We would agree with the use of fire, provided the mitigations and recommendations are considered (Table 2). Obviously, if fuel load is not enough, the other two options would have to be considered. However, there is concern, because large *D. cinerea* shrubs are dominant, and requires double the dose of soil applied arboricides. *C. alexandrii* also requires large doses. There is thus a strong possibility of an overapplication of the arboricide per hectare, increasing non target mortalities. Alternatively, too little arboricide will have a minimal effect and thus be wasteful. Either way, it might prove costly. Therefore, in the absence of sufficient fuel, chopping might be a better option. In this case, an efficient operator, with a good understanding of natural resource management, would mitigate some of the possible negative effects (Table 2). On the other hand, Mr. Vaatz could apply arboricides to the small *A. erubescens* shrubs, and chop the larger *D. cinerea* which are favoured for fire wood and charcoal.

The valuable *Boscia albitrunca* trees are being heavily browsed on the farm, especially by giraffe. Some individual trees could be protected by surrounding with branches cut from nearby thorn bushes This could give those trees a chance to regain vigour over a year or two before the branches decompose. Other trees could then get protected in subsequent years, while thorn bushes nearby would receive some control. The barrier of thorn bushes would need to be wide enough to prevent giraffe from stepping or bending over to reach the leaves of the protected trees.

4.2 Otjisewa
Description of sites including area targeted for bush control:

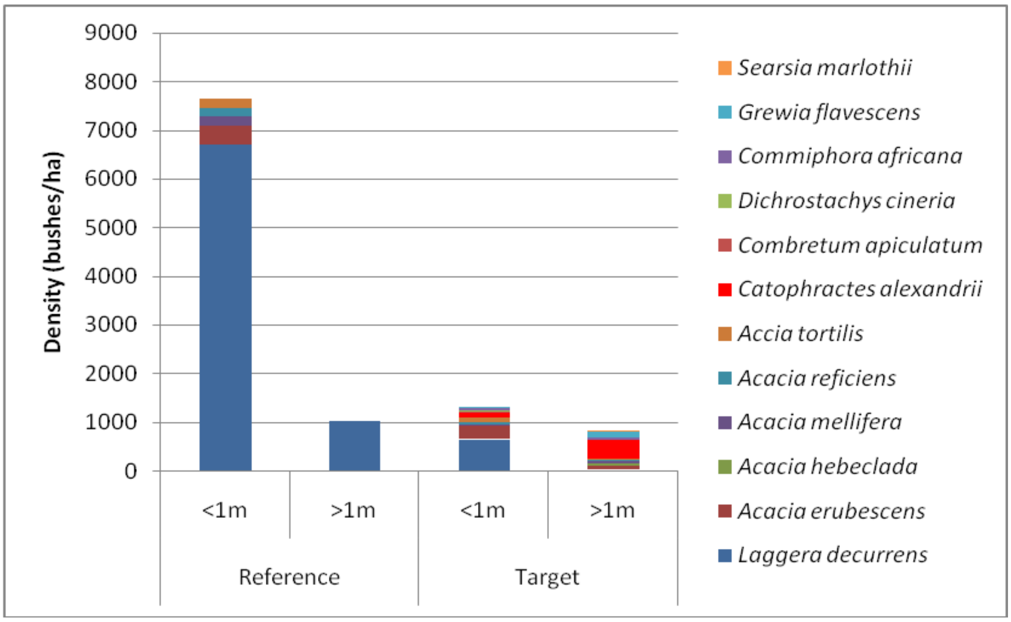

Figure 4: Bush densities at the two measured sites on Farm Otjisewa, divided into species, with encroacher species on the bottom.

Figure 4 shows that very high density of *Laggera decurrens* at the reference site due to arboricide applied three years previously, while at the target site the most dominant species of bush taller than 1m is *Catophractes alexandrii* with a fair amount of *L. decurrens* in the understorey.

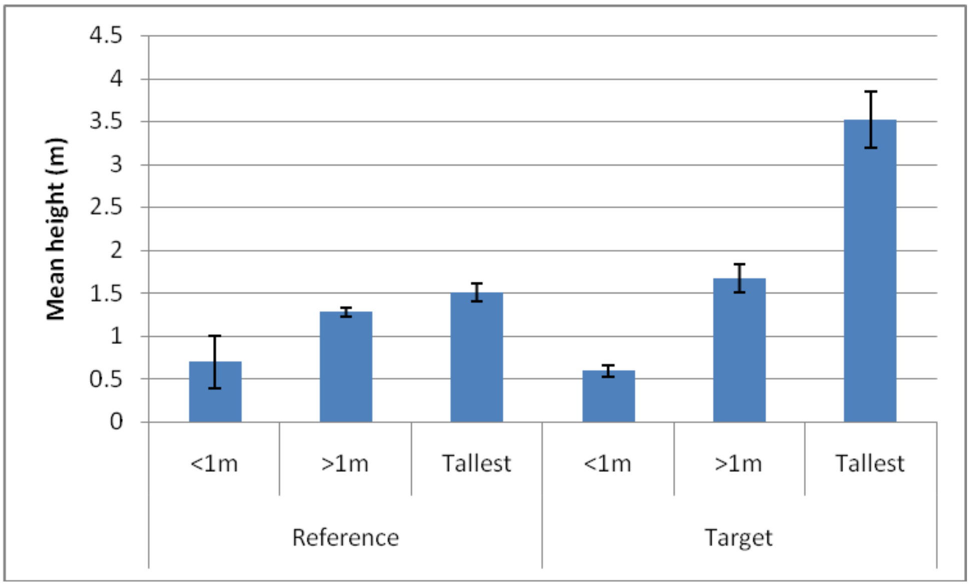

Figure 5: Mean bush heights at the two measured sites on Farm Otjisewa, for three height classes. Error bars represent 95% confidence intervals.

Figure 5 shows the difference in bush height between the two Otjisewa sites, with the reference sites having lower bushes and trees due to arboricide applied three years previously.

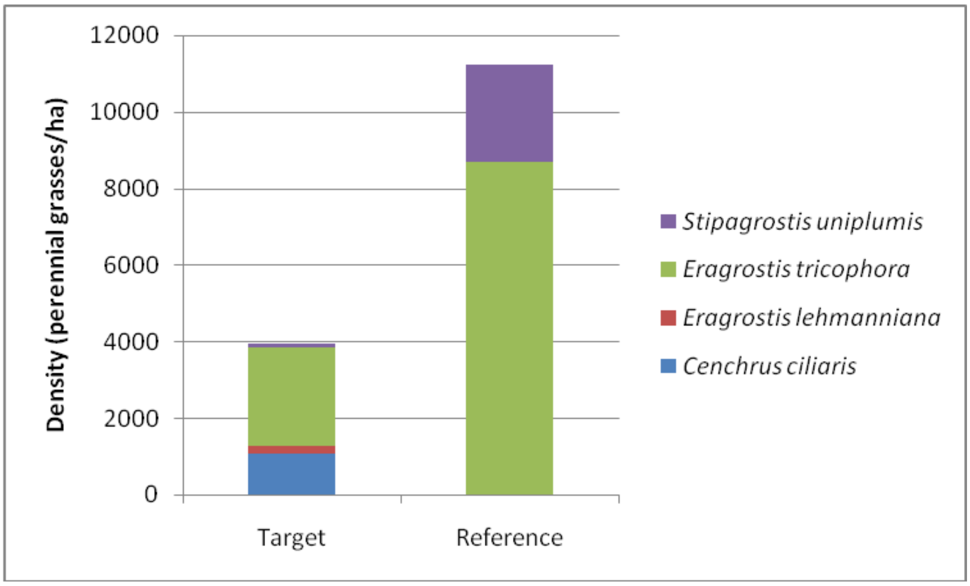

Figure 6. Densities of perennial grass at the two sites measured at Farm Otjisewa, divided into species.

Figure 6 shows that the most dominant perennial grass at the Otjisewa sites is *Eragrostis tricophora*, with a higher density at the reference site where arboricide had been applied three years previously.

Farmer's method:
Mr. Wiss intends to burn some areas, as well as reburn areas that have already been burnt in 2011. In the target area, Mr. Wiss would like to treat the soil with arboricides. Thereafter, he wants to use fire as an aftercare measure, if the fuel load is sufficient. *C. alexandrii* requires larger amounts of arboricide than other species.

Our suggestions:
In the reference area that had been treated with arboricides three years previously, the density of *L. decurrens* was about 8000 individuals per hectare, completely dominating the area and suppressing grass growth, suggesting that arboricides might have exacerbated the situation. Although *L. decurrens* is highly flammable and is likely to support a hot fire in the densities it occurs in, it will most likely recolonise. The seed bank is probably great, and the seeds will germinate and flourish in the disturbed area. In addition, the established plants establish rapidly after fire (Photo 4). We would suggest Mr. Wiss only thins the target area slightly, focussing on woody species < 1m. This will minimise invasion by *L. decurrens* and allow him to maintain the larger trees that will suppress regrowth of saplings. Alternatively, Mr. Wiss could consider a contractor to chop and harvest wood, although this might create gaps for the saplings to grow quickly. Another method, besides the application of soil based arboricides, might be the use of a Tree Popper, to pull out these small saplings. This is a simple lever device, designed in South Africa to pull out woody alien invasive saplings (Appendix 2). This has been tested in Namibia on *A. mellifera* saplings with excellent results. A Tree Popper should be used when the soil is wet.

Photo 4. *Laggera decurrens* resprouting vigorously after fire at Otjisewa

4.3 Monte Christo North

Description of sites including area targeted for bush control:
Due to its proximity to Windhoek, Monte Christo North is in the unfortunate position of attracting poachers who set up many snares. This caused Mr. Rothel to remove all his cattle and take down all the internal fencing a few years ago. Only game animals now use the farm, at a stocking rate of roughly 22 kg liveweight / ha, but most move in and out of the farm.

Photo 5. Fixed point photo at reference site on Farm Monte Christo North

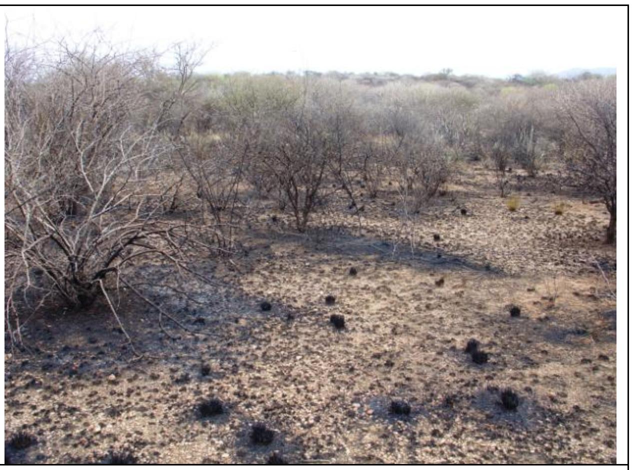

Photo 6. Fixed point photo at site targeted for bush control on Monte Christo North

The target site at Monte Christo had been burnt three days previously. Grass species could, in most cases, not be identified. Instead the perennial grasses were recorded as burnt or unburnt. The tiny perennial grass, *Microchloa caffra*, could be identified by feeling it soft texture. It was excluded from the measurements at the suggestion of Mr. Rothel, due to its insignificant contribution to animal grazing and fire fuel.

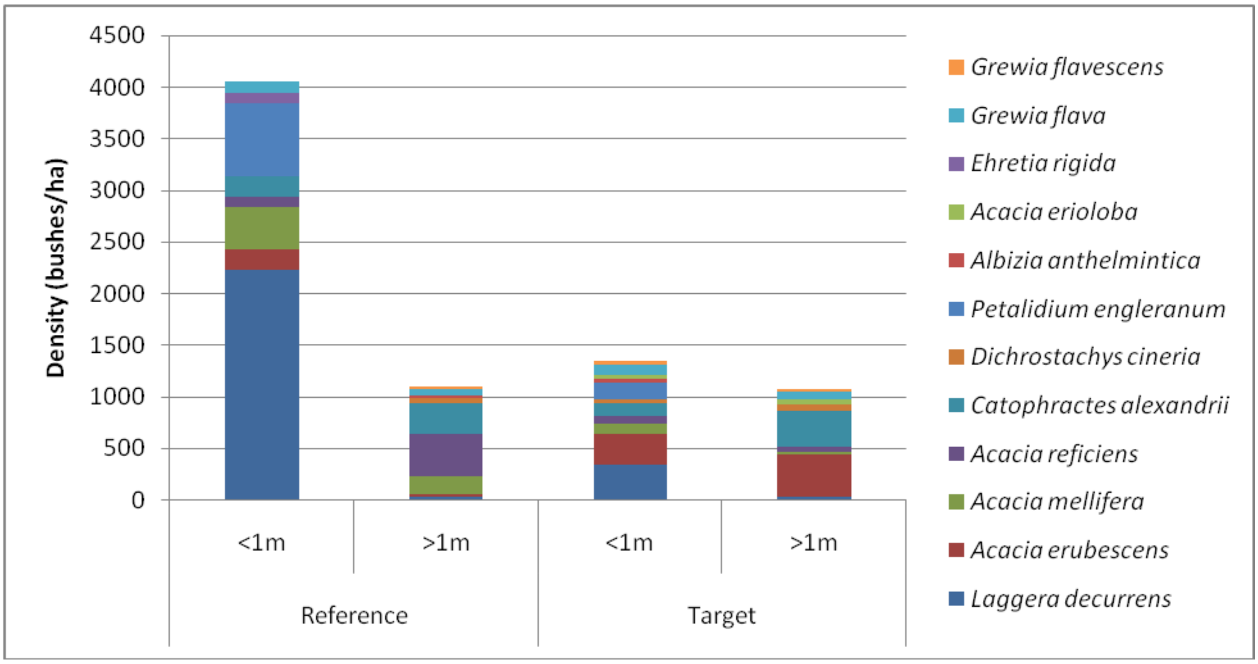

Figure 7. Bush densities at the two measured sites on Farm Monte Christo North, divided into species, with encroacher species on the bottom.

Figure 7 shows that *Acacia erubescens* and *Catophractes alexandrii* dominate the target area. The average height of bushes >1m is 2.2m at the target area, which is slightly lower than the 3.1m at the reference site, probably due to the recent fire. However, *Acacia reficiens* is more common than *A. erubescens* at the reference site.

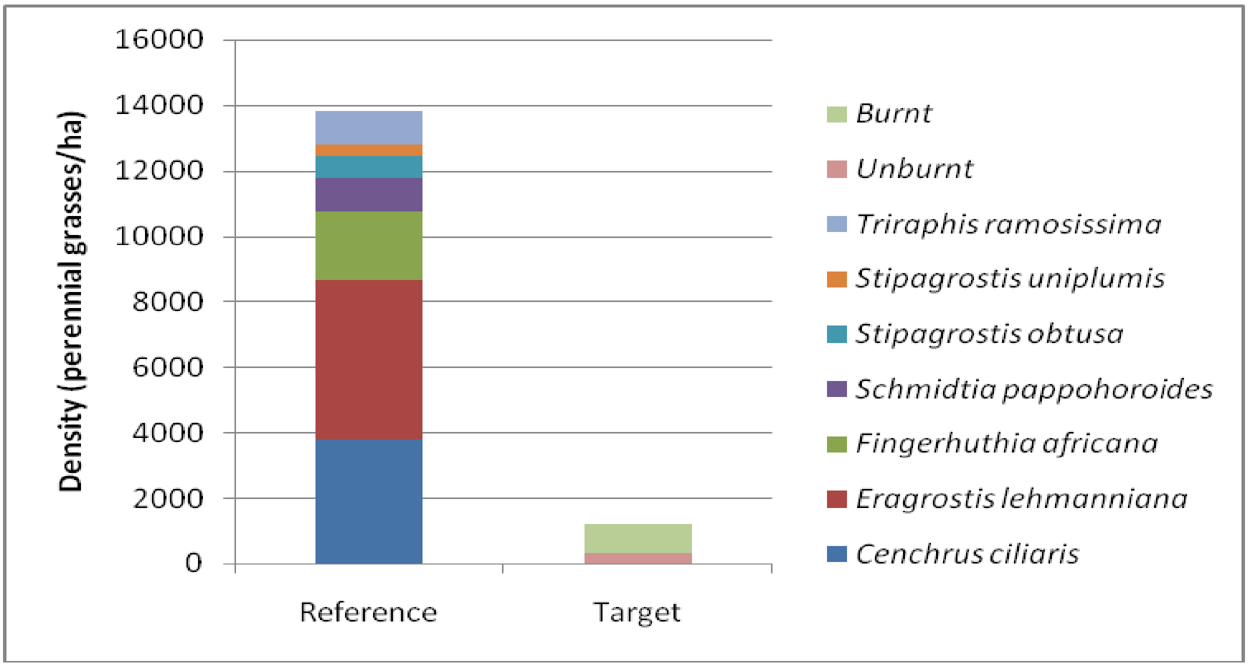

Figure 8. Densities of perennial grass at the two sites measured at Farm Monte Christo North, divided into species for the reference site but only divided into burnt and unburnt grasses at the target site that had been burnt three days previously. The tiny perennial grass, *Microchloa caffra*, was excluded from the measurements.

Figure 8 shows a much higher density of perennial grasses (excluding *M. caffra*) at the reference site. Unburnt grasses comprised 27% of the perennial grasses (excluding *M. caffra*), indicating the weak spread of the fire. The target area had also been burnt the previous year, so it is not surprising that the fuel load was low for the second fire.

Farmer's method:
Mr. Rothel is experimenting with different bush control methods to learn which could be the most appropriate. The methods include bulldozing (Photo 7), fire (Photo 8) and stem burning along roadsides. It would be very useful to document the methods, costs and results, for other farmers to learn from.

Photo 7. Bulldozed site on Farm Monte Christo North.

Photo 8. Fire applied for bush control at Farm Monte Christo North.

Our suggestions:
In areas where bushes are to be cleared by bulldozer, we suggest that a low density of large trees be retained, to suppress the mass establishment of new bushes. In areas where fire is applied, we suggest that fire should not be applied on the same site for two years in succession, but that the fuel load be allowed to build up before re-ignition. The burning of other sites during the intervening year/s will attract game animals away from the previously burnt site and give its perennial grasses a better chance of replenishing their root reserves and building up the fuel load.

4.4 Onduno:
Description of sites including area targeted for bush control:

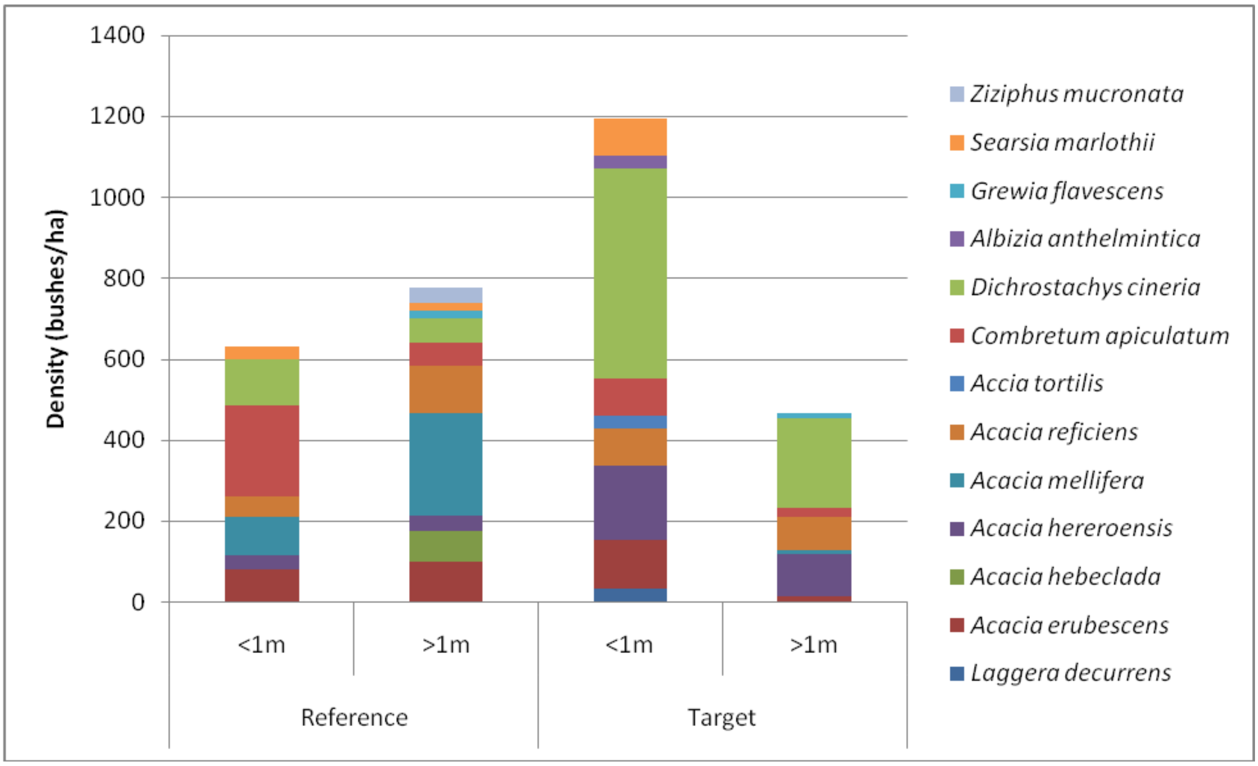

Figure 9. Bush densities at the two measured sites on Farm Onduno, divided into species, with encroacher species on the bottom.

D. cinerea is the dominant species in the target area (Figure 9).

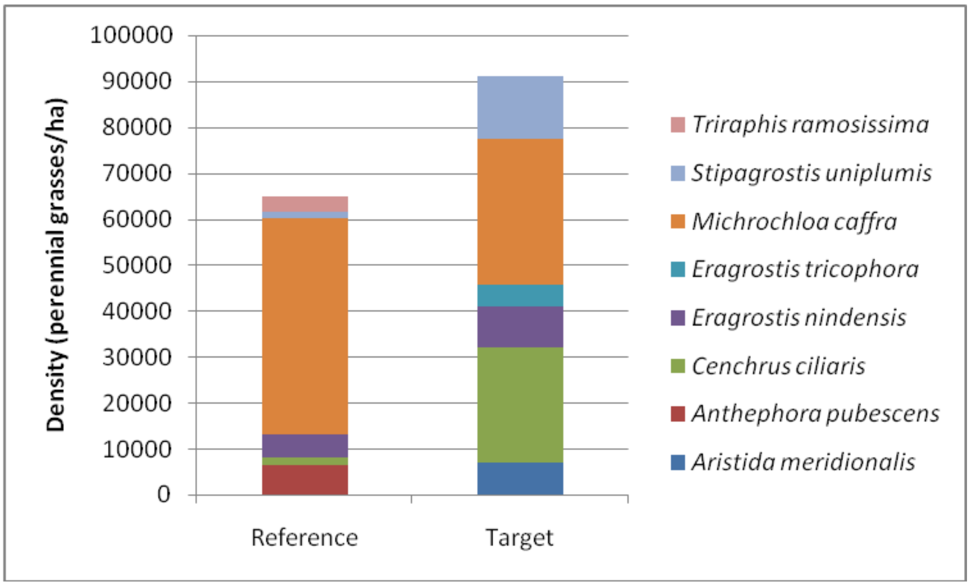

Figure 10. Densities of perennial grass at the two sites measured at Farm Onduno, divided into species

The perennial grass density is quite high (Figure 10), even if the dominant but tiny *M. caffra* is excluded.

Farmer's method:
Mr. Garbade would like to burn the target area, provided sufficient fuel is available. He intends to use arboricides as a follow up, since he feels that burning alone is too slow.

Our suggestions:
We performed the same survey in the area which Mr. Garbade burnt in 2011. The fire had topkilled most individuals of each species, and these were resprouting, with very little outright mortalities occurring. The resprout is all < 1m and so the costs of arboricide application should be much lower. However, the principle regarding arboricides applies, and Mr. Garbade could possibly use fire twice in the space of a few years, to kill the weakened resprout, if the fuel load is sufficient. Since the dominant species in the area to be burnt is *D. cinerea*, browsers such as kudu are likely to limit the regrowth, as *D. cinerea* resprout is very palatable.

4.5 Ombuenja (former portion of Godeis)

Description of sites including area targeted for bush control:
Ombuenja was converted from cattle farm to game farm towards the end of last millennium. Game animals are stocked at roughly 25 kg liveweight / ha, although a small flock of sheep and goats, together with some horses, remain near the newly built lodge.

	
Photo 9. Fixed point photo at site targeted for bush control on Farm Ombuenja	**Photo 10. Bush of *Dichrostachys cineria* on which dieback has occurred twice, on target site at Farm Ombuenja**

The site targeted for bush control at Ombuenja is a narrow strip along the edge of a river valley, containing riverine vegetation that obstructs the view from the lodge into the valley. Mr. Eichorn wishes to reduce the bush density to improve the view for tourists.

The target site has tall trees, with an average height of 7.2m for the tallest tree per 314m^2, comprised largely by co-dominant species of *Acacia karroo* and *A. tortilis*. Many of the *D. cineria* bushes have died back, some of them twice in succession (Photo 10), giving the impression of frost during the previous two winters. However, Mr. Eichorn believes that the dieback resulted from exceptional rains waterlogging the soil too long for *D. cineria.*

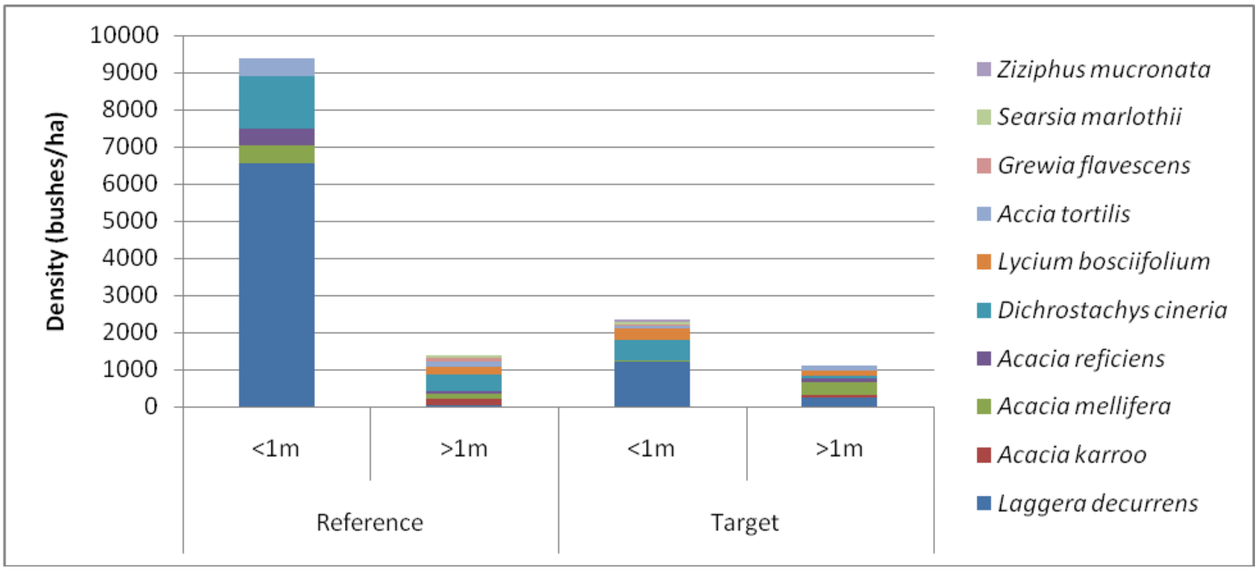

Figure 11. Bush densities at the two measured sites on Farm Ombuenja, divided into species, with encroacher species on the bottom.

Figure 11 shows that the main bush species targeted for control would be *Acacia mellifera* and *Dichrostachys cineria*.

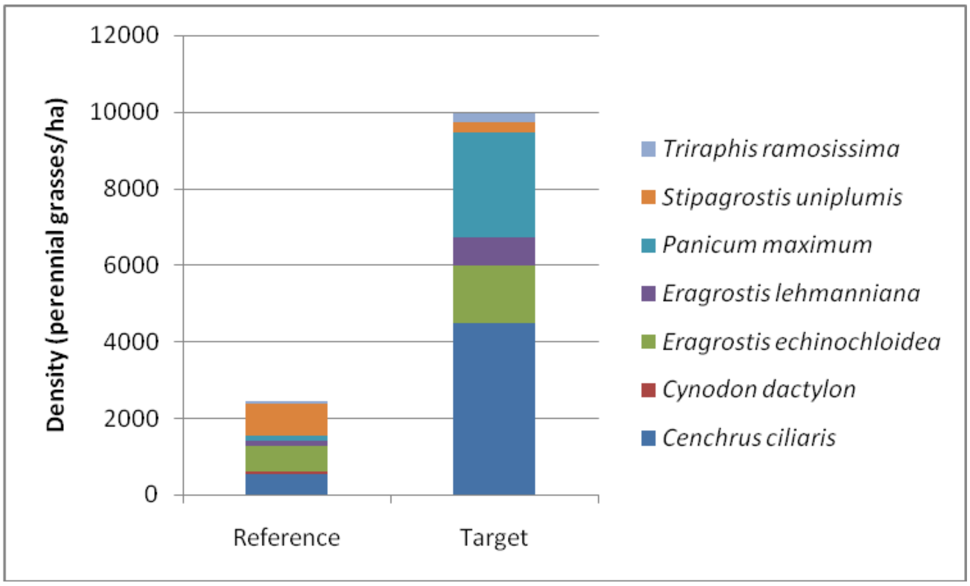

Figure 12. Densities of perennial grass at the two sites measured at Farm Ombuenja, divided into species.

Figure 12 shows a much higher density of perennial grasses at the target site, counterbalanced by a higher density of *L. decurrens* at the reference site (Figure 11). The latter is situated downstream from the target site and closer to a deep dam dug into the river bed.

Farmer's method:
Mr. Eichorn prefers the use of arboricide for selectively targeting *Acacia mellifera* and *Dichrostachys cineria*. He does not wish to target *Acacia erubescens* due to its important contribution to the food supply of game animals.

Our suggestions:
If arboricide were to be applied to the target site, there is a risk that tall trees could be killed. The site is so small, occupying roughly 1ha, that manual clearing of *A. mellifera, Lycium bosciifolium* and *Laggera decurrens* could be applied for treatment and followed up in subsequent years. The Tree Popper could be used for small saplings of *A. mellifera*. It is very likely that the surviving resprouts of *Dichrostachys cineria* will be browsed off by the goats.

4.6 Monitoring programme
It is important that the monitoring programme that was set at each of the five farms is continued. Students in the field of Natural Resource Management, under guidance, could assist with this.

5. Feasible economic utilization of harvested bush

Bush encroachment hinders productivity on some of the commercial farms sampled, reduces underground water, and has negative effects on the Namibian economy.
Results of the survey carried out with five targeted farms demonstrate that farmers are using a range of methods to combat bush encroachment, each with limited results:
1. Fire – Instead of destroying the problematic bush species, fire often causes coppicing of bush.
2. Manual and mechanical bush clearing–The density of the bush makes manual clearing time-consuming and costly, and the cost of machinery, fuel and maintenance for mechanical bush clearing is prohibitive for most farmers.
3. Selective arboricides – Chemicals application is expensive and farmers are concerned about the potential long-term environmental risks.
Interviewees at the five farms reported that they have not been able to turn mitigation of bush encroachment into an economic opportunity. However, there are some examples of Namibian farmers who have successfully used bush as a raw material to generate income.

The successful initiatives to turn bush encroachment into business opportunities have largely been due to farmers adopting a number of different methods concurrently.

Options to turn bush encroachment mitigation into income
A multi-faceted approach is necessary to combat bush encroachment and in turn, to turn bush encroachment into an economic opportunity, and the following are examples of the options currently employed in Namibia.

5.1 Charcoal production

A combination of charcoal and wood production can be implemented as bush encroachment mitigation measure. Farmers can choose to produce charcoal on their own or subcontract this activity to a private company. In a case where the farmer would like to do it himself, guidelines for charcoal production (as per Namibian Agricultural Union) should be followed.

The charcoal industry in Namibia, which started in 1990, but picked up after 2000, has received bad press over the past year due to allegations of bad labour practices. Despite the obvious difficulties to establish the exact number, there are about 4,800 workers and a recorded 280 charcoal producers (Diekmann, 2011). The main areas of production are in the districts of Grootfontein, Otjiwarongo, Outjo and Tsumeb. Farmers around Gobabis have also started producing charcoal recently. About 50% of the producers are emerging farmers who try to diversify their income streams while fighting invader bush encroachment. The industry relies on migrant workers (primarily from the Kavango and north-central regions), who are considered as self-employed contractors and not as employees, and are paid between N$300 and N$550 per ton for sifted or unsifted charcoal. Most of these workers do not have contracts with the farmers, which has led to the claims of unfair labour practices.

Charcoal production presents a viable option as the charcoal market is well-developed. Currently there are eight Namibian charcoal processors who purchase charcoal, process it and distribute it to different markets. It could also be used as a soil amendment or biofilter to purify dirty water, such as that being released by the new poultry farm into the river that runs through the green belt.

Table 8. Name and contact details of Namibian charcoal processors.

Company name	Contact person	Telephone number	Cellphone number	Email address
Jumbo Charcoal	Ian Galloway	062-503 838	0811281711	jumboch@iway.na
Hans Steyn	Hans Steyn	067-242386	0812791599	wildevy@iway.na
Etosha Charcoal	MaansRobberts	067-313797	0811284572	etoschar@iway.na
Superbraai	Patat du Toit	067-235016	0812887763	patat@mweb.com.na
JJ Loots ENC & Blaze	JJ Loots KokkiePrinsloo	067-235008	811292174 0812922442	lootsjj@iway.na
Fire & Flame	Piet & Magda Prinsloo	067-313857	0812780408	Not available
Kilo 40 (Ignite)	Gerhard Steyn	Not available	0812338795	kilo40@mweb.com.na

According to Jumbo Charcoal, one of the biggest charcoal producers in the country, they export a combined 25,000 metric tons of barbeque charcoal to South Africa, Europe and the Mediterranean and the demand is always above supply.

Table 9. Prices offered by Jumbo for charcoal per ton.

	Sieved					**Bulk**
			INDICATIVE FARM GATE PRICE -example only			**Bulk Price**
PRICE N$/TON excl. VAT			Lumps	Fines	3% sand and ash	
	+20 mm	Fines	+20 mm	(3-20mm)	**Estimate N$/Mt**	
FSC (Forest Stewardship Council)	**1450**	**700**	78%	19%	**1,264.00**	**N$ 1200 -**
NON FSC	**1350**	**500**	78%	19%	**1,148.00**	**N$ 1100-**

Jumbo subsidize transport by paying N$0.85c/ton/km of charcoal delivered at their premises in Okahandja. This amount can be paid directly to farmers as well who organize their own transport. This has been a convenient arrangement particularly to farmers north of Okahandja as often there trucks that travel up north and come back empty. This has not been easy for farmers south of Okahandja because transport has always been an issue.

Jumbo, like some of the other charcoal processors, has contracted a consultant to guide farmers on charcoal production. They have also provided farmers with kilns or material to make their own kilns. Farmers can pay back in tonnages of charcoal. For farmers to qualify for this support a minimum of 30 tons is required to be supplied to Jumbo. This figure has never been a determining factor but rather an assurance to Jumbo by the farmer that he is producing the charcoal.

With various price options offered by Jumbo, farmers can choose to sell their charcoal for a sieved or unsieved (bulk) price, at FSC or non FSC rates.

5.2 Wood production

What seems to be an obvious approach to the bush encroachment is to manually chop down the bush and sell it as wood in Windhoek's formal and informal settlements. A challenge is that this could pose a threat of land degradation as wood harvesters are interested in bigger stems which are more valuable for wood. Most of the bush observed in the sample sites is not big enough for economically suitable fire wood.

Despite the challenges, some of the woody materials can be turned into firewood and sold directly to consumers in the immediate areas. A ton (usually a bakkie load) can fetch between N$500 – N$1500. Small stems of bushes, particularly those of *Dichrostachys cinerea*, could be sold and recommended to be used in some of the energy efficient stoves (see below). These stoves can take any burnable material of small enough size. Some initiatives are underway by Non-Governmental Organisations, such as the Desert Research Foundation of Namibia (DRFN), to promote energy-efficient stoves, but there is a long way to go before the stoves become the preferred cooker of choice for Namibians in informal settlements. Other stoves use the wood gasses for heating while the charcoal can be used as biochar for improving the soil or the health of animals that consume it (Zimmermannn & Amupolo, 2012).

5.3 Energy for Future bush clearing approach

Energy for Future is a sister company to Ohorongo Cement Company, which is based north of Otavi at the cement plant. The company utilizes high-end technology to harvest wood from neighbouring farms. Farmers are charged a nominal fee for the bush clearing service, and the company uses the bush to fire their kiln. The resultant ash is used as a component in cement production. There is ample wood for Energy for Future. They plan to only concentrate on harvesting bush in a 75 km radius around their plant. By harvesting only half of each farm's bush-encroached areas, they estimate that they will have enough wood for the next 80 years of operation. To put it into perspective, they are only harvesting 6% of the entire country's bush encroached area. The Energy for Future's partnership model, where a private company absorbs some of the cost burden of bush clearing in return for using the bush for alternative purposes (whether for cement/charcoal/firewood production), could be considered. There are other initiatives being considered closer to Windhoek, and the price offered for wood is likely to rise steeply over the coming years.

6. Cost estimate for commercial bush control

6.1 Manual bush clearing

If farmers consider using a company to carry out manual de-bushing, they can use as a guide the prices that Nampower pays when they give out tenders to clear the bush around power lines country-wide. The contractors selected by Nampower are tasked to strip a 20 metre-wide clearing along power lines. The amount that contractors usually get paid for manual clearing is of all bush works out at roughly N$600/ha. This figure gives farmers an indication of the labour costs for clearing. The rate can go down depending on the density of the bush per area to be cleared and also the fact that it will not be a total clearing but selective clearing. This method makes it possible to protect high-value tree species, especially protected trees.

6.2 Arboricide application

The Namibian Meat Board sells arboricide from China. The table below summarizes the active ingredients and prices.

Table 10. Arboricide sold by Namibia Meat Board

Arboricide	Active ingredients	Source	Amount (N$)	Application
Tebuthiuron	Tebuthiuron (liquid form)	China	152.65/liter only comes in 5 liter Total per 5 liters -763.25	Apply on base of the tree 1.5liter with 8.5 liters of water – useful in sandy area
	Tebuthiuron (granules)		676/ 10kg box	Apply at the base of the tree before it rains – useful in all kinds of terrain.
Bromacil	Bromacil (powder)		140.75/ kg x25 kg bag Total per 25 kg – 3518.75	Dilute with water 1 kg to 10 liters of water, spray around the base of the tree - stony area

Table 11. Agra products for controlling bush encroachment

Arboricide	Active ingredients	Source	Amount (N$)	application
Brushfree SC	Bromacil (liquid form)	South Africa	999/5l	1 litre to 5 litres water, spray bottom and leaves
	Bromacil (powder form)	South Africa	1700/ 25 kg	Information not available from supplier
Molopo	Tebuthiuron (powder)	South Africa	2700/20kg	Information not available from supplier

The effectiveness of the active ingredients depend not only on the chemical composition of the arboricides themselves but rather on a range of factors i.e. the species to be treated as well as the methods of application.

6.2.1. Aerial application of arboricide

According to Namibia Agricultural Distributors, the use of aircraft to treat a large area is much more efficient. This method ensures immediate, reliable and cost effective application. The cost for aerial application of arboricide is N$115/ha just for the aircraft. The cost of the arboricide depends on its application rate. At 7.5kg/ha it would come to N$675/ha for the arboricide.

6.2.2. Manual application of arboricide

For selective manual application, labour charges are approximately N$15/kg of arboricide to be applied. That would work out at N$105/kg arboricide plus labour. A contractor who does manual application reports that it takes his team of 10-12 workers four days to complete 200-300 ha selectively.

Due to the different ways of charging for application of arboricide, aerial application works out cheaper than manual application of 3g / bush if the bush density is over 2500 / ha (Figure 13).

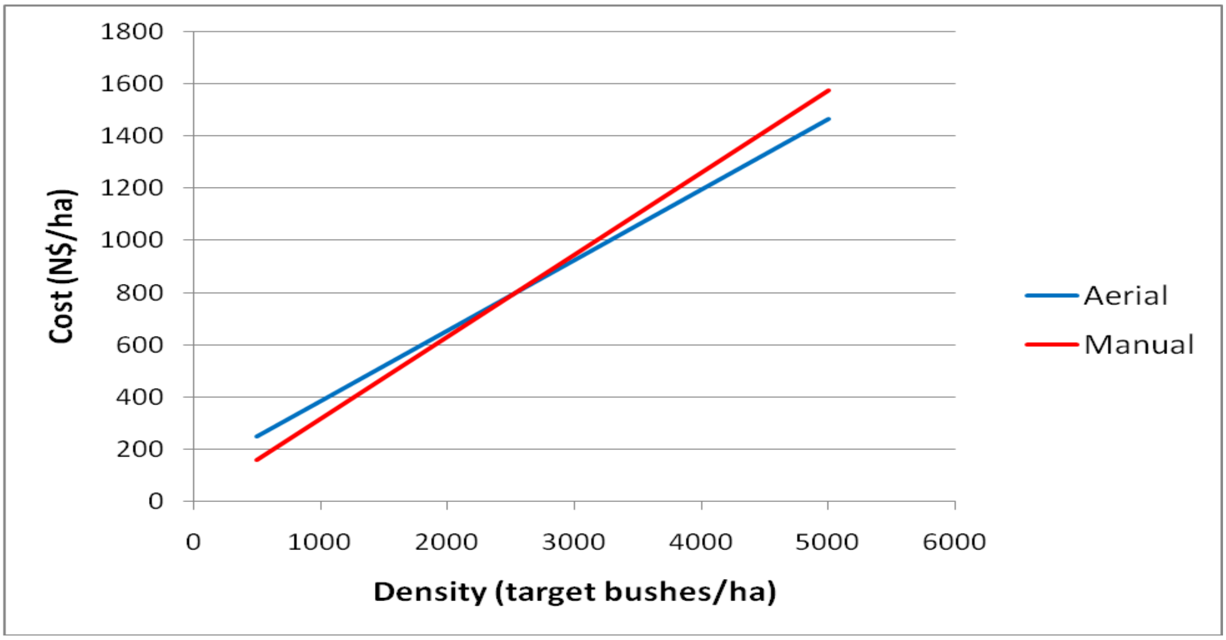

Figure 13. Comparative costs of aerial and manual application of tebuthiuron per hectare, assuming an application rate of 3g per bush.

Table 12. Example of dosage per tree for Destroyer Mono Granule arboricide (active ingredient Tebuthiuron) as provided by Namibia Agricultural Distributors cc.

Bush Species	Common English name	Dosage g/tree Up to 2m Height	
		Soil Clay Content	
		0-20%	21-31%
Acacia erubescens	Blue-thorn	2.0	4.0
Acacia hebeclada	Candle acacia	2.0	4.0
Acacia hereroensis	Mountain thorn	2.0	4.0
Acacia karroo	Sweet thorn	1.5	3.0
Acacia leuderitzii	Bastard Umbrella thorn	2.0	4.0
Acacia mellifera	Black-thorn	1.5	2.0
Acacia newbrowni	Water-thorn	1.5	3.0
Acacia reficiens	False Umbrella thorn	1.5	3.0
Acacia tortilis	Umbrella thorn	1.5	3.0
Catophractes alexandrii	Trumpet thorn	3.0	6.0
Dichrostachys cinerea	Sickle bush	3.0	6.0
Grewia bicolor	Bastard Raisin	2.0	4.0
Grewia flava	Velvet Raisin	2.0	4.0
Grewia flavescens	Sandpaper Raisin	2.0	4.0
Rhigozum trichotomum	Driedoring	1.5	-
Stoebe vulgaris	Bankruptbush	1.5	3.0
Tarchonanthus camphoratus	Camphor bush	1.5	3.0
Terminalia sericea	Silver cluster leaf	2.5	-
Ziziphus mucronata	Buffalo thorn	2.0	4.0

7. An exploratory review of drainage ecosystem characteristics and associated management priorities in the Windhoek Greenbelt

By Dr Hugh Pringle, Ecosystem Management Understanding (EMU)™

7.1 Overview of the Greenbelt area's drainage systems health and bush encroachment

This area has remarkable healthy drainage ecosystems considering its predominantly upland (erosional) nature and topography (steep slopes and narrow depositional valleys are common). They appear to be relatively resilient to incision and accelerated dehydration that affects rangelands through most of Namibia (Shamathe, Zimmermann et al. 2008; Pringle, Zimmermann et al. 2009; Pringle, Zimmermann et al. 2011) and beyond (Cooke and Reeves 1976; Pringle and Tinley 2003). Why exactly the upland valleys of the Windhoek Greenbelt appear resistant to major incision processes can only be speculative in an exploratory investigation such as this. Some possibly influential factors include:

1. Valley soils are hard setting or protected by pebble mulch and therefore resist incision
2. Watering points may be away from high energy flows and livestock and wildlife may travel mostly across rather than up and down these usually sensitive parts of farms
3. Tracks are perhaps not generally cut into the landscape below natural level and hence do not provide nickpoint intitials for donga development

The reality on different farms (and even different parts of farms) may involve combinations of these and other factors. This area would be a valuable case study to compare with other areas of markedly more incised upland valleys in order to better understand what factors predispose or protect these ecologically and commercially important parts of the broader landscape from landscape incision, "unplugging", dehydration and bush encroachment.

7.2 The more usual process state (condition)

The scarcity of sharply incised valley floors and aggressive donga heads in this project area is in sharp contrast to the majority of Namibia's effective catchments (those with readily recognisable drainage features and substantial surface flows). In the more usual situation, the depositional surfaces that dry out last as seasons decline have become incised by dongas formed by "nickpoints". These nickpoints in the land start donga headcuts (the active "waterfall face") that move upslope and split wherever they encounter strong flow from multiple directions (Pringle et al., 2011).

The depositional surfaces are often seasonally inundated – their soil profiles remain saturated or nearly so for long periods after substantial rains and surface flows. This usually means they support a particular suite of species adapted to repeated seasonal waterlogging. Such species are often termed "hydromorphic", which literally means water loving. They are often grasses or grass-like plants and found only in these seasonally waterlogged areas. In healthy seasonally inundated areas, more common species are usually confined to better drained niches such as convexities ("bumps") or adjacent to and inside freely draining channels. This is because these more common species' seedlings (which may be numerous) are usually all killed by drowning in healthy waterlogged areas. However on "bumps" and in freely draining channels, the soil may dry out quickly enough to allow seedlings to survive. As these seedlings grow and develop strong root systems, they expand the area around them in which similar seedlings can survive in a positive feedback loop (facilitated dehydration of larger areas around initial places of establishment). There is evidence of this incision-based facilitation and thickening happening in some otherwise very sparsely treed valleys on Farm Dusternbrook and Farm Otjisewa, the two Farms in which exploration was conducted using Google Earth Pro® (see Figures 1 and 2). However, these examples appear to be the exception, rather than the norm.

There are two very common causes of loss of waterlogging and bush species encroachment;

1. Roads cut into the landscape and acting as drains
2. Animal paths (particularly cattle paths) that draw water to them and instigate donga development.

A less common factor is drainage interception and redirection, whereby natural flows cannot reach these waterlogged areas and hence they dry out far more quickly than before. This redirection may be due to a blockage (e.g. a dam or major bunding feature) or due to an incision that takes water away (e.g. a deeply cut down road). Dam by-washes (where excess water is released) are often poorly planned and release excess water as a strong “jet” of water that inevitably encounters a small nickpoint downslope and initiates donga development. It is important that dams are located primarily according to where excess water can be spilled gently rather than “jetted” downslope. It is a myth that major channels are required for an effective dam - of far more importance is the frequency of flows and the depth of the dam (hence more persistent water availability versus evaporative loss).

Below a few key considerations for “fitting” land management to landscape drainage processes are addressed. They include:

1. Planning, installing and maintaining tracks
2. Avoiding animal path formation
3. Maintaining groundcover.

7.3 Considerations for minimising the risk of donga development and bush encroachment of upland valley floors

7.3.1 Planning, installing and maintaining tracks

Ideally tracks should be as high in the landscape as is feasible and along the contour of the land (*across*, rather than *up-and-down* slope). Valley floors will inevitably have to be crossed for effective access to all parts of a farm. However, these should be minimised as they involve having to travel *up-and-down* slope and should be along as gentle a slope as possible (preferably along spurs that spill away in both directions away from the proposed track. Crossing valleys can also increase the risk of disrupting natural waterlogging as described above; by diverting and/or draining these ecologically and commercially critical areas. Where this crossing is unavoidable, it should be carefully planned to be in a low energy section (e.g. not near a sharp channel bend) and at right angles to the flow and valley slope. Critically, such channels should never be dug into the land surface and preferably be at natural landscape level, even if reinforced by imported material. This will allow natural flows and reduce the time a road is not usable after a flow event.

The development of tracks at natural landscape level is important everywhere and yet is a rarity. Most access tracks are dug into the landscape and have a row of soil along each margin; the “windrow”. Dug down tracks divert flows and can start erosion upslope in areas of stronger run-on to the track. The windrows also divert flow and often breach at an area of stronger flow, thus increasing flows in already susceptible areas and “droughting” the areas that used to receive the diverted sheet flow.

Repairing “track creeks” is often a major challenge because so many tracks are altering natural sheetflows. A careful priority setting process can be helpful and lead to gradual restoration of natural surface flows, commencing with most important areas. This repair work may simply require bringing in the soil for the windrows; the amount of soil stored in these drainage diverters is easily underestimated. However, if the track is still effectively a drainage ditch, then it may be necessary to install trafficable track bunds to take water out of the track and spill it gently away. These bunds should release track water onto gentle, stable slopes to avoid creating new erosion problems that will end up cutting back into the track.

Where a track is clearly in a poor location and it is likely to continue to create important alteration to natural flows, it should be replaced with a well planned alternative and shut down. Shutting down a track requires rehabilitation as described above as well as possibly “s-ripping” the old track surface between any bunds. S-Ripping simply means ripping the surface in a manner like entwined snakes, which avoids flows accelerating down straight rip lines. As bunds will not need to be trafficable, they need not be rolled and so should be much quicker to construct. All bunds should be built on deep ripped platforms so that the bund forms a solid core below the land surface. Simply dropping material on the unprepared surface makes a far weaker bank that is likely to need ongoing repairs.

7.3.2 Avoiding animal path formation

Animal pads draw water to them and concentrate it so that it speeds up and becomes more erosive. Incised animal paths are very common causes of donga development and this is often evidenced by old paths leading directly up to the headcutting donga (and often a new path alongside the donga).

With cattle, a primary cause of deep path incisions that initiate dongas is the location of water places in the lowest part of the local area. This enables cattle to move in single file (as is common for them) up and down the most fragile, actively flowing parts of farms. Even if dams are used, it is preferable to pipe the water to a quieter, more stable part of the local grazed area to minimise path formation within the areas of more concentrated drainage.

Continuous grazing management exacerbates animal path formation because paths never have the chance to silt up and heal. Rather they gradually become deeper and more likely to initiate a donga. Rest-based grazing management has allowed animal paths to recover on some cattle stations in central Australia (and they have grass almost up to the trough). The best, but most labour intensive way of addressing this issue is by herding livestock, so that impact of hooves can be managed –and in some cases has been used to heal shallow dongas and scalds. My Uncle has used his animals to break down a donga system and adjacent scalds near Tarkastad in the Karoo of Southern Africa (although he kraaled the animals in the affected area for a few days, a few times as he does not herd his cattle and sheep). I have also seen successful examples of this on the African Centre for Holistic Management's Dimbangombe Ranch in western Zimbabwe.

In southern Africa, some game species share the trait of trailing along parts of the landscape most vulnerable to donga development. Oryx are such a species and when an area is to be destocked, denying access to water will help minimise this risk (and improve the quality of "rest").

Check fences within a camp can also be used to make all animals walk out of the valley floor. These may be the actual camp fence, or a constructed barrier within the camp at a vulnerable place. Care should be taken to make it clearly visible if in the camp. Fencing or bushes can be used. Thornbush fences may be more effective than conventional cattle fences in blocking game.

Poorly located fencelines may encourage animals to trail up and down particularly vulnerable areas and these should either be moved or have occasional check wings to move animals away.

7.3.3 Maintaining groundcover

Maintaining groundcover leads to more infiltration, slower flows and protected soil surfaces. However, there are many instances in Namibia and across Australia's rangelands where dongas are cutting back into perfectly healthy country. Groundcover helps minimise and slow donga expansion, it does not prevent dongas. Dongas are caused by nickpoints and will cut back from there left untreated because of the cavitation, even if the "waterfall" is weak. Healthy groundcover within a donga can help slow water and trap sediment to gradually refill and heal the donga.

The key to maintaining good groundcover is grazing management, which includes well known issues such as:

1. Getting the stocking and utilisation rates right and at the right time
2. Allowing adequate recovery before resuming grazing if using a rest-based strategy
3. Transforming moribund grass into litter “nature’s mulch”.

There are many grazing strategies to choose from nowadays, the key in this context is to use one (well) that achieves the desired outcomes.

7.3.4 Repairing incised systems

Conventional soil conservation tools are adequate to deal with these problems, though locally innovative approaches have been developed by farmers in Australian and southern African rangelands. They are often cheaper and use locally available resources.

What is most important is to adapt a systems view that involves identifying the fundamental causes of the incision process and then the key control points in which to intervene cost-effectively to “flip” systems back to health (Tinley and Pringle 2006) (see Appendix 3).

The causes and repair of this problem are a focus of a SASSCAL Project Proposal submitted by the Polytechnic of Namibia and recently approved by the SASSCAL Directorate. The author of this report and Dr Ken Tinley are also completing a manual for farmers regarding this understanding of rangelands in Australia and it may well be modified to suit Namibian conditions and include Namibian examples through the proposed SASSCAL project.

7.4 Summary of drainage issues

The Windhoek Greenbelt has strong upland topography and narrow valley systems that would normally be considered highly vulnerable to landscape incision by donga development and spread. This is not the case, though in the areas of sharper incision associated with dams in valley floors, there is evidence of substantial bush encroachment. Developing a better specific understanding of why these valleys are not incised as is common elsewhere in the region and across Namibia more broadly will substantially enhance our broader understanding of this generally pervasive and debilitating problem (to both livestock enterprises and most wildlife).

Some explanation is provided of the causes and processes associated with bush encroachment that is driven by incision of seasonally waterlogged landscapes and some suggestions are provided for consideration by those wishing to minimise the risk of the problem.

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Appendix 1. Agricola article that discuses bush control in the context of causes of bush encroachment

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A PROBLEM TREE TO DIAGNOSE PROBLEM BUSH

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ABSTRACT

The term "problem tree" refers to a conceptual model used as a diagnostic tool to analyse a sequence of events that leads to a problem (such as bush encroachment in rangelands). A problem tree is useful because the consequences of different interventions can be visualised and understood more easily in diagrammatic form, thereby guiding management decisions regarding the problem. A problem tree was constructed to show multiple causes of bush encroachment. It was generalised by considering many possible causes, and not only those applying to particular areas of encroachment or specific species of bush. If the problem tree is to be useful in decision-making, one needs to determine which of the multiple pathways are of greater significance in any particular situation. Management decisions are bound to be more effective in the long run if they address causes higher up in the tree and closer to the root causes, than the proximate causes or symptoms at the bottom of the tree.

INTRODUCTION

Problem trees

The term "problem tree" refers to a conceptual model used as a diagnostic tool to analyse a sequence of events that eventually leads to a problem (Fussel, 1995). The tree is usually built upside down, with its roots, representing the root causes, at the top. When drawing a problem tree, the symptom is noted at the bottom of the diagram or page with its proximate cause immediately above it, and with a short arrow pointing downwards, from cause to symptom. The cause is determined by the question, "Why (does this symptom occur)?". This procedure is repeated until the root cause is reached, towards the top of the page. Since ecological interactions tend to be complex, with multiple determinants, the arrows in an ecological problem tree tend to grow out into branches.

Diagnosis through drawing a problem tree is useful in guiding the management of the problem. Not all branches of a problem tree are relevant to every situation and land users need to identify which branches have the greatest relevance to their problems. Management decisions that address causes higher up in a problem tree, closer to the root causes, are likely to be more effective in the long run than those that address proximate causes or symptoms at the bottom of a tree.

Bush encroachment

Bush encroachment occurs in about 260 000 km^2 of Namibia (Bester, 1999), or about 30 % of the surface area of the country. Species of indigenous bush that contribute to bush encroachment include *Acacia mellifera, A. reficiens, A. luederitzii, A. erubescens, A. fleckii, A. nilotica, Colophospermum mopane, Dichrostachys cinerea, Terminalia prunioides*, *T. sericea* (De Klerk, 2004); *Grewia flava* and *A. tortilis* (Moleele, Ringrose, Matheson & Vanderpost, 2002). Widespread and excessive bush density seems to be a problem resulting largely from mismanagement of rangeland (de Klerk, 2004). However, bush encroachment can also be viewed as a natural patch dynamic process (Britz & Ward, 2007: Meyer, Wiegand, Ward & Moustakas, 2007), with the landscape consisting of many patches in different states of transition between grassy and woody dominance.

METHODS

Problem trees were constructed for various environmental problems, as teaching exercises during environmental awareness workshops. The bush encroachment problem tree was started with the symptom, “bush encroachment”. The tree was developed by repeatedly asking “Why (does this symptom occur)?”, until the root causes were reached. The tree produced during the workshops was developed further through informal discussions with farmers as well as the authors’ research. The problem tree was generalised by considering all possible causes, and not only those applying to a particular bush-encroached area or a particular species of bush. Diverse views on the causes of bush encroachment were considered, including well-established, speculative, controversial and anecdotal views.

RESULTS

The problem tree appears in Figure 1. The causal linkages below are numbered; the numbers in brackets refer to the numbered arrows in Figure 1.

DISCUSSION ON PROBLEM TREE CONSTRUCTION

Availability of soil water

Bushes encroach when established bushes grow bigger (1), and when new bushes are recruited (2). The growth of previously established bushes occurs every year, although more so in years of good rain. If more soil water is available to bush roots (without prolonged waterlogging), bushes grow more vigorously (3). Greater soil water also allows more bush seedlings to establish (4), provided there are enough viable seeds (5). If more soil water is available to *Acacia mellifera* roots, more pods with viable seeds are produced (6) (Joubert, Rothauge & Smit, 2008). In fact, there is generally no production of viable seeds in below average rainfall years, whereas very many seeds are produced in exceptionally high rainfall years.

The establishment of new bush seedlings tends to be an extremely episodic event, occurring on average once every few decades. This is particulary true for *A. melllifera* (Joubert *et al*., in press). A good rainy season leads to prolific flowering during the following dry season, after which viable seed is produced in the next rainy season. This seed also needs good rain to ensure survival after germination. A third good rainy season may be needed to ensure successful establishment of the small seedlings from the previous season. Hence recruitment of *A. mellifera* may require two or three consecutively good rainy seasons (7), for linkages 4, 5 and 6 to take place.

Although there is no arrow in the problem tree pointing towards the box with successive good rainy seasons, this is not a root cause, but rather a rare environmental prerequisite for the establishment of bush seedlings of certain species, if at least one of the root causes has taken effect. Other species such as *D. cinerea* may be able to establish with one season of exceptional rain, since they produce viable seed banks (due to hard seed coats) (Bell & van Staden, 1993). There is a distinction between species such as *A. mellifera*, which have seeds that cannot survive in the soil from one season to the next and species such as *A. tortilis* with small seeds and hard testa that survive for many years in the soil seed bank. Establishment of *A. tortilis* seedlings therefore do not require an initial wet season for seed production.

The soil water available to bushes is directly related to the water that is removed by grass roots (8). If grasses are dense and/or vigorous, less water is available (Mworia, Mnene, Musembi & Reid, 1997) (9). This is straightforward competition between bushes and grasses, regardless of whether their roots occupy two different layers in the soil as postulated by Walter (1971). This competition is also influenced by differences in osmotic potential and wilting points between woody plants (that use the C3 photosynthetic pathway) and grasses (that use the C4 photosynthetic pathway). Generally grasses utilize soil water faster than woody plants, but reach wilting point sooner, with soil water at a higher matrix potential above the wilting point of woody plants (Smit & Rethman, 2000).

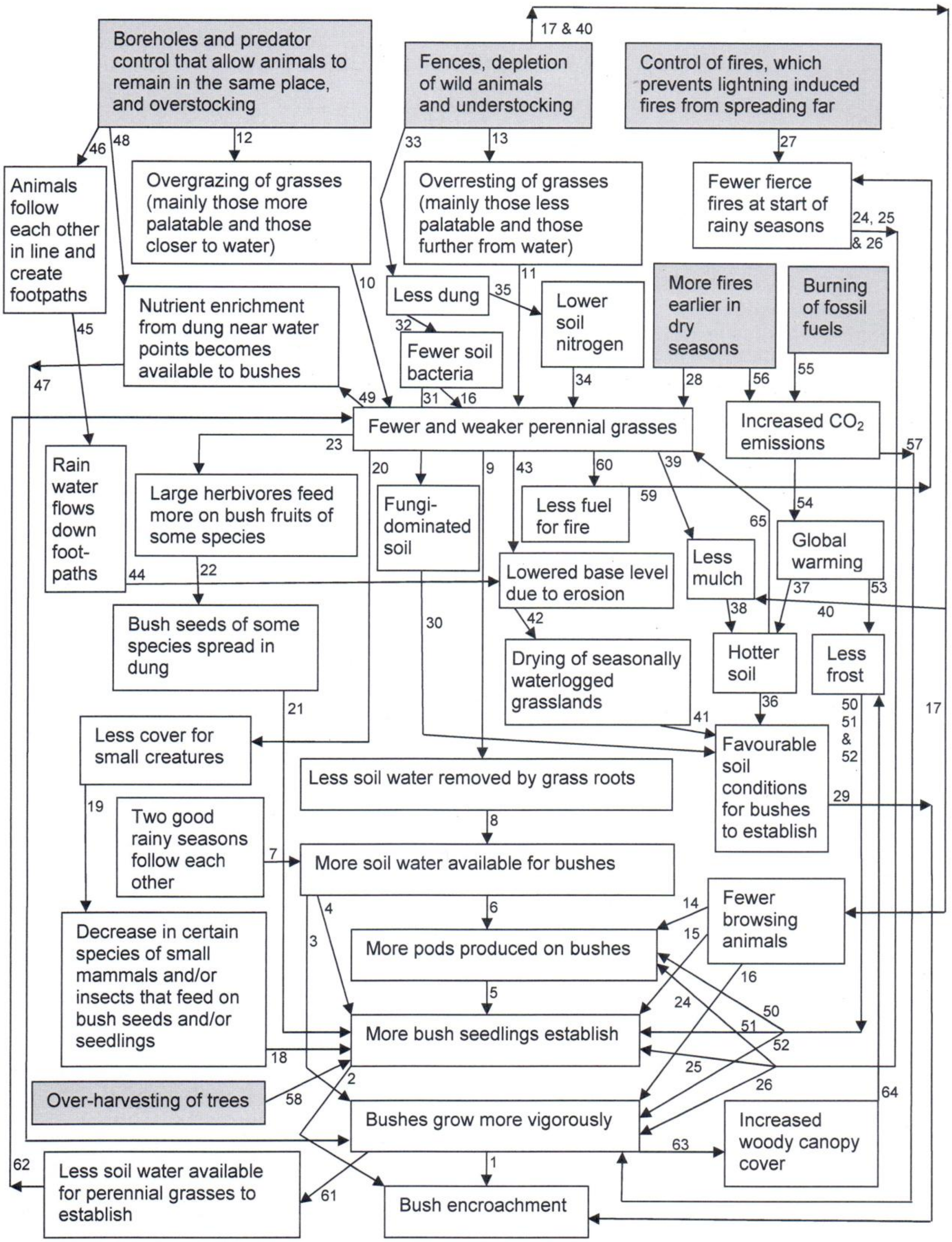

Figure 1: A diagnostic problem tree for bush encroachment, with root causes shaded and numbers providing references to text.

Grazing herbivores

Perennial grasses evolved under conditions of severe grazing followed by periods of long rest. They can become weakened by extremes in either direction, namely by overgrazing or overresting. Both conditions can occur on the same rangeland, if animals are stocked lightly and continuously or under fast rotation with short rest, as occurs on many commercial farms. The most palatable grasses, especially those closest to the water point, then become overgrazed (10), while the less palatable species, especially those further from the water point, become over-rested (11), both resulting in lowered grass vigour (McNaughton, 1979). Historically, under natural conditions, the predominant species of wild herbivores remained tightly bunched in large herds controlled by predators. Permanent water sources created ideal opportunities for predators to ambush prey and it is unlikely that herbivore herds would have remained in the vicinity for long periods. Wherever the herds grazed they are likely to have fouled the rangeland with their dung, making it unsuitable for regrazing until cleaned by dung beetles and rain, by which time the severely grazed and trampled grasses would have replenished root reserves and would thereby have been ready to be regrazed (Savory, 1999). The natural movements of animals were disrupted by pioneer farmers who replaced the wild herbivores with domestic livestock; controlled the predators; changed the natural range by sinking boreholes and putting up fences; and thereby allowed overgrazing and undergrazing to become widespread (12 & 13) thus contributing to the root causes of bush encroachment.

Browsing herbivores

Another reason why bushes flourish is because of a reduction in browsing animals which allows more pods to be produced on bushes (14), more seedlings to establish (15) and established bushes to grow more vigorously (16). Browsing, mainly by kudu, goats and impala, was found by Roques, O'Connor & Watkinson (2001) to impact on encroachment, mainly on *Dichrostachys cinerea*, and only in the early stages of encroachment. Although browsing by ruminants may actually stimulate bush growth (Scogings, 2003; Stuart-Hill, 1988), megaherbivores such as elephant and black rhino previously played an especially important role by keeping bush growth in check (Grossman & Gandar, 1989). These large megaherbivores have been seriously depleted due to the construction of fences and hunting (17). Small browsing herbivores such as hares, squirrels, gerbils and bruchid beetles feed on bush seeds and/or seedlings. In fact, small browsers may be more important regulators of bush densities than previously recognised (Ostfeld, Manson & Canham, 1997; Weltzin, Archer & Heitschmidt, 1997). A decline in small browsers allows more seedlings to establish (18). Declining grass cover may be responsible for the decline in some small browsers (19), which is due to perennial grasses being fewer and weaker, thereby rejoining the main trunk of the problem tree (20). Bush seedlings of some species increase because large herbivores browse the pods and disperse the seeds (21) (Coe & Coe, 1987). This applies especially in the dry season when palatable grasses are in short supply, to bush species with tasty pods and seeds with hard testa that can survive animal digestive systems. *D. cinerea and A. tortilis* are dispersed in this way, especially if there is insufficient palatable grass available, forcing grazing animals to feed more on pods (22). However, the seeds of other woody species (such as *A. mellifera*) which do not have hard testa, cannot survive, and cannot be dispersed in this way. The lack of palatable grasses again leads back to the main trunk of the problem tree through fewer and weaker perennial grasses (23).

Fire

Bushes also flourish because of fewer hot fires at the start of the rainy season, when bush stems are more sensitive having broken dormancy so that their phloem is active and buds are exposed. Fierce fires tend to burn in years following high rainfall when a high fuel load is produced and there are fewer large herbivores to reduce the fuel by grazing. After good rains the bushes produce many pods, which are consumed by the fire (24), preventing them from producing viable seed. Small bush seedlings and saplings are sensitive to fire; they are probably also destroyed in fires of lower intensity (25). Well-established bushes usually only suffer top kill from hot, high intensity fires, although they may be weakened due to loss of food reserves (26), especially if their regrowth is browsed (Trollope, 1980). Lightning often causes natural fires at the start of rainy seasons. These fires occur during the short window period when the availability of dry fuel overlaps with the occurrence of thunderstorms. However, effective fire fighting by commercial farmers over the past decades has resulted in such fires being quickly extinguished or contained within firebreaks (27), further contributing to bush encroachment.

Despite fewer fires at the start of the rainy season, there has been an increase in fires earlier in the dry season, usually as a result of negligence or vandalism. Perennial grasses evolved under the selective pressure of fire at the start of rainy seasons. They are thus not well equipped to deal with fires early in the dry season (or in winter), which tend to weaken the grasses (28). These early fires break the dormancy of the grasses, exposing their new shoots to unfavourable conditions (dryness, continuous grazing and possibly frost). These hardships are ameliorated at the start of the rainy season but impose their toll if the rainy season is still far away. Bushes on the other hand, are far less affected by fires early in the dry season, since they are dormant with inactive phloem and buds well protected by bark. Therefore, the balance between bushes and grasses tends to favour bushes if a fire burns early in the dry season, contributing to the root causes of bush encroachment.

Soil conditions

Some soil conditions, other than those related to competition for soil water mentioned above, may also favour bush encroachment (29). Soil dominated by fungi favours bushes (30) while soil dominated by bacteria favours grasses (31) (Kingdon, 2005). Dung is dominated by bacteria so less dung results in fewer bacteria in the soil (32). Less dung is produced if large herbivores are fewer (33), one of the root causes of bush encroachment already mentioned. Lack of dung beetles to process dung, resulting from the use of chemicals to control parasites, which simultaneously contaminate dung, can lead to fewer bacteria in the soil.

C4 grasses are in greater need of soil nitrogen than leguminous C3 bushes that house nitrogen-fixing bacteria. Lowered soil nitrogen may therefore weaken grasses (34) more than bushes (Kraaij & Ward, 2006). Soil nitrogen is lower if there is less dung. (35).

Higher soil temperatures seem to favour the establishment of bushes (36) (Labuschagne, pers. comm.). Soil temperatures increase as a result of global warming (37) and when there is not enough mulch to cover and shade the soil (38). A scarcity of mulch results if grasses are fewer and weaker (39), and if there are fewer animals to trample down dry grass stands (40).

Soil conditions in specific locations can influence the growth of bushes. For example, seasonally waterlogged soils tend to be dominated by a good grass cover because bushes suffer if waterlogged. Although covering only a small proportion of Namibian rangeland, these hydromorphic grasslands are key habitats that provide important resources for livestock and game. Bushes are likely to flourish if water is drained from waterlogged soil (41) as a result of erosion that lowers the base level (42), which formerly held the water back (Pringle, Watson & Tinley, 2006). According to Pringle (2008), “base level incision is clearly etching away some of Namibia’s most productive, drought-buffering landscapes at very local to whole of catchment levels of ecological organisation”. The base level erosion is usually a result of depleted perennial grass cover (43) and often of water flowing down footpaths (44); brought about when herbivores (cattle) slowly follow each other (45) especially when walking to and from a water point supplied by boreholes (46) in the absence of large predators. Another local effect is that established bushes often grow vigorously near water points, often developing into valuable shade trees. Animals rest under these trees and devour the masses of pods that are normally produced. The trees/bushes benefit from nutrient enrichment of the soil from dung (47) of animals attracted to the water point (48) (Moleele & Perkins, 1998). There is no competition from grasses (49), since they do not survive due to continuous trampling by animals. Dung from animals supplemented with phosphate lick is likely to improve soil fertility even more, considering the low availability of phosphorous in Namibian soils; however, much of it is wasted if allowed to accumulate in the sacrifice zone around water points, benefiting only a few desirable large shade trees.

Climate change

Warmer temperatures result in fewer bush pods being killed by frost (50), fewer seedlings being killed by frost (51) and fewer established bushes experiencing top kill (52), especially of the more frost-sensitive species such as *Dichrostachys cinerea*. In encroached stands the bushes are less susceptible to damage by cold (frost), compared to more open stands, since many bushes in close proximity to each other are somewhat protected. (Smit, 1990). Less frost may result from global warming (53), caused by increased carbon dioxide and other greenhouse gas emissions (54), and the burning of fossil fuels (55) and bush fires (56). Increased carbon dioxide emissions favour the growth of C3 plants, including bushes (57), over C4 plants, including grasses of semi-arid rangelands (Midgley, Bond, Roberts & Wand, 2000), especially under xeric, rather than mesic conditions (Palmer & Eamus, 2008).

Loss of large trees

The loss of large trees due to harvesting for fence posts or charcoal/firewood, or through indiscriminate/non-selective bush-control measures, is a root cause of bush encroachment (58). Large trees outcompete smaller bushes (Smit, 2004), and when large trees are cut down, the smaller bushes increase in size.

Positive feedback

The problem tree has four positive feedback loops that reinforce some of the causal linkages, further favouring bush encroachment. Fewer and weaker perennial grasses result in less fuel for fire (59), reinforcing fewer fierce fires at the start of rainy seasons (60). Increasingly vigorous bushes remove water from the soil (61), leaving less for perennial grasses, thereby reinforcing fewer and weaker perennial grasses (62). The increasingly vigorous bushes also provide greater canopy cover (63), which creates a microclimate with less frost (64). Hotter soil reinforces fewer and weaker perennial grasses (65) due to poor germination of perennial grass seeds in soil much exposed to the sun, while favouring the germination of weeds such as *Tribulus terrestris* and bush seedlings (Labuschagne, pers. comm.). The increase of biological soil crusts under impenetrable *Acacia mellifera* bushes (Thomas, Dougill, Berry & Byrne, 2002) may also provide a positive feedback loop by restricting water infiltration to grass roots (Eldridge, Zaady & Shachak, 2000). However, there may also be negative feedback since the density and vigour of annual grass under bushes is often greater than between bushes, so the benefits of shade and leaf mulch provided by bushes may outweigh the disadvantages of some biological soil crusts. In addition, the crusts that tend to develop on soil under bushes may contain more beneficial organisms that fix nitrogen, protect soil from wind erosion and possibly enhance water infiltration, since biological soil crusts can be extremely diverse in both species composition and properties (Eldridge & Greene, 1994). Because the role of biological soil crusts in bush encroachment is not entirely understood, they have not yet been added to this problem tree; however, this can be done once this issue has been clarified.

DISCUSSION ON MANAGEMENT APPLICATIONS

It is necessary to determine which of the multiple pathways in the problem tree are of greater significance in any particular situation, if the tree is to be useful in decision making. Pathways will differ, depending on factors such as land-use and rainfall history, agro-ecological zone, soil conditions and the species of bush that are considered problematic. For example, Midgley and Bond (2001) suggest that fire contributes more significantly to bush dynamics in higher rainfall areas while rainfall contributes more significantly in lower rainfall areas. They further suggest that herbivores in higher rainfall areas exert their influence on bush dynamics largely by consuming fuel load, which in turn reduces the occurrence, extent and effectiveness of fire. In lower rainfall areas herbivores probably influence the dynamics largely by feeding on bush seedlings and saplings. The problem tree has five shaded boxes containing root causes. It is unlikely that more than three of them would apply to a particular situation, and most likely that one will be of overriding importance. If management is applied within the problem tree, at an intermediate cause, then the arrow pointing down to that cause will show which factors, above it, are likely to counter the effectiveness of the management efforts. Final problem trees for specific circumstances will appear less complicated than the large, generalist problem tree in Figure 1. Even if specific trees appear complicated at a glance, they become ever clearer when interpreted one step at a time. A Powerpoint presentation is ideally suited to this purpose, as small amounts of information are released at intervals, making the construction of the complete tree easier to follow. If farmers are involved in the construction of a problem tree, discussion is stimulated and a more holistic understanding of the problem develops.

Treating the symptom

Farmers commonly react to bush encroachment by wanting to treat the symptom, usually by means of a "quick fix", such as the application of arboricide. Observations in the field show that widespread aerial application of arboricide appears to result in other "problem" species becoming dominant after the targeted bushes have died. For example, *Laggera decurrens* has been observed to replace dead *A. mellifera* and *D. cinerea* thornbush. Apart from the high cost of this "solution", it may simply bring temporary relief until the root causes (still in place) result in further bush encroachment. However, if the root causes have indeed been addressed, the simultaneous treatment of the symptoms may be justified to ensure a quicker recovery of the rangeland.

If arboricide is opted for, application costs can be minimised by selective application, at critical times, such as when bushes failed to produce viable seed. This would prevent the sprouting of masses of seedlings after the parent bushes had died. It may be more economical to apply arboricide as a follow-up treatment some years after another method has been used. The arboricide then only needs to be applied to those target bushes that were not sufficiently weakened by the previous treatment. Arboricide may also be applied to cut stumps in conjunction with selective chopping, to prevent regrowth. Selective thinning can structure the surviving bushes in such a way that their roots will suppress the re-establishment of excessive replacement bushes while encouraging grasses (Smit, 2004).

With increasing worldwide demand for energy it is likely that manual chopping will become a viable option for many farmers. There is a risk that chopping will be insufficiently selective, or favour the chopping of bigger bushes over smaller ones to maximise wood yield per unit of effort. This may lead to rangeland degradation due to exposed soil, as does the non-selective application of arboricides.

Treating root causes

Since the root causes of widespread bush encroachment are related to human interference in nature, treatment would mean reverting to nature. This could only be achieved if neighbouring farmers were to join forces to form large conservancies, temporarily close down water points, removing fencing and re-introducing megaherbivores and other wild animals exterminated in recent centuries to their farms. Since the above is highly impractical, the next best alternative would be to treat intermediate causes as close as possible to the root causes. The root cause that is the easiest to treat is the disruption of natural fire regimes, through the combination of regular fire control and the infrequent application of strategically timed burning. The root cause of over-harvesting would require lengthy treatment if few or no trees remain, requiring protection for tree seedlings over the decades as they are sensitive to browsing.

Focusing on perennial grass

The box with fewer and weaker perennial grasses features prominently in the problem tree and it holds the key to bush encroachment through a multitude of pathways, and to its management. Perennial grasses can be kept healthy by alternating short grazing periods with long rest periods in the growing season, allowing grasses time to replenish their food reserves. Vigorous perennial grass cover may weaken bush seedlings and saplings through competition for water, but whether it prevents the establishment of the young bushes or not is still debatable (Kraaij & Ward, 2006; Joubert et al., 2008). A soil rich in manure, well worked in by dung beetles, seems to favour grasses while causing premature weakening of mature bushes by fungal disease, as indicated by the sound of a hollow thud when striking the main stem with a heavy stick (Richardson, pers. comm.).

Reversing rangeland dessication

Where there is massive loss of water from the rangeland as a result of soil erosion, instead of slow infiltration, the root causes need to be addressed, but it is important to treat the symptoms at the same time. If a gully is eating its way towards a seasonally waterlogged grassland, repair of the gully will save the grassland from bush encroachment (Pringle, *et al*., 2006). A gully system can be healed by the strategic placement of filters to slow down flowing water and trap sediment, provided that the root causes of the gullies have also been addressed. In cases where dense bush grows nearby, this problem can be converted into a solution, by providing filter material for the gully system (Shamathe, Pringle & Zimmermann, 2008).

Occasional use of fire

There are many risks associated with the use of fire, including the accidental spread of fire to other areas and the possibility that there will be insufficient rain after the fire to allow proper recovery of the burnt grass. One way to minimise the latter risk is not to use fire unless the residual soil water from the previous season is sufficient to allow the grass to recover, even without follow-up rain (Labuschagne, pers. comm.). Since fire consumes organic matter that would otherwise be added to the soil, it may be wise never to use fire unless sufficient organic matter has built up in the soil over previous years.
Situations where burns may be warranted are: after exceptionally heavy rains resulting in high grass yields that cannot be consumed by available animals; where it may be beneficial to open up bushy areas; or to remove the threat of mass seed production by bushes. Perhaps the most important role that fire can play is to kill off a mass emergence of bush seedlings to prevent a new wave of encroachment during the limited time that bush seedlings and saplings are sensitive to burning (Joubert *et. al*., 2008).

CONCLUSION

The problem tree is one of several tools that can assist decision making on appropriate rangeland management. The constructed tree is by no means inflexible, and can be revised as new information becomes available. It can be more effective if used in combination with other tools, such as a state and transition model (Joubert *et al*., 2008); a decision support system for rangeland management (Joubert, Zimmermann & Graz, 2008), accessible at http://chameleon.polytechnic.edu.na/wiki/; and a farmer's conceptual model of rangeland dynamics (Zimmermann & Smit, in prep.).

The problem tree is based on a wide range of information sources including informal observations. Some aspects thus need further research before assertions can be verified. For this reason, greater emphasis should be placed on research into the dynamics implicated in the overall process of bush encroachment in Namibia, such as the demographic studies proposed by Midgley & Bond (2001).

Since problem trees are aimed at controlling problems, there is a risk that bush, rather than excessive bush, will be perceived as the problem. In their natural environment all species of bush, whether encroachers or not, perform useful ecological functions. Most rangeland management aims at achieving a reasonable balance between bushes and grasses, so that each may contribute to a healthy and productive rangeland.

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Appendix 2: The Tree Popper

The Tree Popper is a simple levering device designed by Mr. Terry Negis in Somerset West, South Africa. In 2012, trials in Namibia suggested that the Tree Popper could be a useful tool in the control of *A. mellifera* saplings (and most likely other encroaching species). Because a large amount of the root system is removed, no follow up is needed. In the wet season, the success rate was around 94 %, but only 50 % in May. It is therefore important to use the TreePopper when the soil is moist and friable, in the wet season, for maximum effectiveness.

Fig 1: The Tree Popper in action, pulling out an invasive *Acacia* from Australia in South Africa. (photo from T. Negis).

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Appendix 3: Key Principles and Steps in Catchment Repair in Arid Rangelands

Ken Tinley and Hugh Pringle
Ecosystem Management Understanding (EMU) Project™
Range Management Newsletter 7(2): 4-5

These notes were prepared for attendants of an EMU catchment ecology and restoration workshop held in Alice Springs in April 2007 and hosted by Centralian Land Management Association, funded by the National Landcare Programme. The notes were prepared after the workshop in response to HP's perception that there seems to be a culture of restoration based on "what should we do here?", rather than stepping back and assessing where the bang for the buck will be to fix the big picture problems.

We present here a checklist of key activities and associated principles to help guide those planning and implementing repair of water flows and longer lasting positive soil moisture balances arid rangelands. We emphasise the word "repair", rather than "restore" in recognition that complete restoration to pre-disturbance functioning may not be possible, but something much better than current degraded states is usually possible.

We also emphasise the necessity to undertake thorough investigation, assessment and planning before deciding on any course of action. In other words, we stress the importance of starting with thorough investigation and being led by a plan, rather than by particular tools (e.g. ponding banks or scrub filters).

Where, what, and why does a particular area(s) require repair?

It is very important that any repair project has clear objectives and activities planned as a guiding strategy in terms of e.g. location, type of intervention or whether a site could likely self-repair if protected by exclosure.

1. Gather whatever air photos and satellite images are accessible and use them to plan a flight over the area of interest and its surrounds. Use the air photos and satellite images with subsequent observations and digital photos taken during low-level flying (100 to 200m above ground level) to choose where to visit on the ground as a groundtruthing exercise.
2. Consider all the information gathered in point 1 above and synthesise it, preferably in a small group. Record your assessments of key features on a clear overlay over a satellite image or contour map showing infrastructure of the area (preferably have a land system map with infrastructure and satellite image at the same scale so they can be used interchangeably.
3. In what part of the catchment is the area to be recovered; headwaters, middle, lower, coastal (or salt lakes). Is this area the main catchment or a tributary to a bigger system?
4. Locate and map drainage bottlenecks (including at the keyline), channel junctions and rock bars.
5. Map gully heads and major rill heads. These active features are critical points to be stabilised first in any repair project as they are migrating upslope with every rainfall event making the situation worse and more difficult to repair.
6. If a floodplain, floodout, pan or lake is involved, has it become perched above effective flooding/recharge except in exceptional rainfall events?
7. Have these run-on/into surfaces changed from a grassland/sedgeland into (or towards) scrubland? Identify the indicators of a drying change (e.g. *Acacia tetragonophylla* and other acacias).
8. Determine base-levels at drainage key points ("critical control points") to be stabilised and repaired (restored if feasible) that will allow a return to "normal" or "usual" flood levels and frequency to inundate run-on/into areas effectively. For example, these key points may be a sill around a pan, a gully head stripping a floodout or a breached rock bar in a major channel.
9. Identify the floodout and exit points of floodwaters onto and out of the flooded area.

10. Map or sketch the landscape pattern (aerial view) and site cross-sections. Identify for example, depth of channel incision as demonstrated by exposed roots, position of river pools (e.g. behind rock bars or on outer curve of a bend in the river channel), condition and impacts of threats (e.g. gully head breaching or excessive damage from stock breaking down banks and consequent silting up.
11. When a whole drainage unit is to be addressed, at any dimension or scale, *always* start at the head or source of that unit and work downstream from there to the next tributary junction or drainage bottleneck, where transverse (across-flow) water-ponding and slowing structures can most effectively be positioned (e.g. "sausage roll" of wire mesh or crushed rock and geotextile structure).
12. Of critical importance is that valley-side tributaries can flood run-on/into areas frequently from relatively light rainfall events, whereas main river or creek floods, when deeply incised, will only floodout with the infrequent, major rainfall events. Thus, for more frequent flooding, valley-side tributaries are of paramount importance.
13. Assess and map infrastructure impacts: positions of tracks, roads, fencelines and artificial watering points in relation to area being repaired.
14. All road/track/pad/fenceline "rivers" to be redirected to their original drainage pattern. Establish bunds across the eroding "rivers" and help restore natural flows in-between (e.g. floodways).
15. Take before and after fixed point photographs as a minimum of monitoring.

There is quite a bit of background investigation, assessment and overlay mapping to be done!

But now (and NOT before), you are ready to open the toolbox of repair options and start planning what to do where.