An assessment of the economics of land degradation related to bush encroachment in Namibia

Namibia Nature Foundation

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List of acronyms

BAU	Business As Usual
CICES	Common International Classification of Ecosystem Services
ELD	Economics of Land Degradation
EPA	Environmental Protection Agency
FAO	UN Food and Agriculture Organisation
GIZ	Deutsche Gesellschaft für International Zusammenarbeit
LDN	Land Degradation Neutrality
MA	Millenium Assessment
MAWF	Ministry of Agriculture, Water, and Forestry
MET	Ministry of Environment and Tourism
MLR	Ministry of Land Reform
NAU	Namibia Agricultural Union
NIRP	National Integrated Resource Plan
NPV	Net Present Value
ResMob	Resource mobilisation for effective implementation of the updated biodiversity strategy in Namibia
SCC	Social Cost of Carbon
SEEA-EEA	UN System of Environmental Economic Accounting: Experimental Ecosystem Accounting
SOC	Soil Organic Carbon
TEEB	The Economics of Ecosystems and Biodiversity
TEV	Total Economic Valuation
UNCCD	United Nations Convention to Combat Desertification

Executive summary

Bush encroachment has increased significantly in Namibia over past decades, largely as a result of habitat change. It affects an estimated 26 to 30 million hectares of land in Namibia, although this figure is currently under review. Overgrazing is thought to be a key driver of bush encroachment, but the displacement of browsers by livestock, the suppression of high intensity fires due to cattle farming, rainfall and its variability, and increased atmospheric CO_2 concentrations are also likely contributors.

Bush encroachment has negative impacts on some of Namibia's key ecosystem services, such as livestock production, groundwater recharge, and tourism, as well as biodiversity. This has given rise to calls for an extensive programme of de-bushing, to reduce bush encroachment and try to reverse some of these negative effects. De-bushing also offers economic opportunities for the utilisation of woody biomass via charcoal and firewood production, electricity generation, and other means.

This report seeks to delineate and assess the state of bush encroachment in Namibia, identify ecosystem services impacted by bush encroachment, and evaluate how flows and stocks of these services would likely change under a programme of de-bushing. Where possible, key ecosystem services are valued and these values are fed into a cost-benefit model to estimate the net benefits of de-bushing when compared with a business-as-usual (BAU) scenario of no de-bushing. This study follows the methodology of the Economics of Land Degradation (ELD) Initiative.

The delineation of bush encroachment is based on Bester's (1999) data, updated by Honsbein et. al. (2009). According to this data, bush encroachment is present in most regions of Namibia, affecting multiple ecosystems and land uses, but particularly commercial and communal agriculture and tourism. This makes it a complex problem, as impacts can vary depending on the immediate environment (e.g. types of soil, other vegetation, wildlife), how the land is used (e.g. cattle farming, tourism), and how many people depend on the land. Furthermore, the appropriate method, range, and scope of de-bushing activities are also dependent on the local context.

To identify the ecosystem services affected by bush encroachment (and de-bushing), this report adopts the Common International Classification of Ecosystem Services (CICES) in order to remain consistent with the draft Inventory of Ecosystem Services in Namibia (2015) and the UN System of Environmental-Economic Accounting (SEEA). The CICES classification recognises three broad categories of services: provisioning, regulation and maintenance, and cultural. Given data and research constraints, we are unable to quantify the likely impacts of de-bushing on the majority of services. However, there is reason to believe that many of these services would be positively affected by de-bushing, which suggests that there is upside risk to our estimates of net benefits.

Some key assumptions underpin the valuation of ecosystem services under a scenario of de-bushing. It is assumed that 60% of the bush-encroached area can be targeted for de-bushing, that bush densities would be reduced by 67% (or 33% in a key alternate scenario), and that 5% of the targeted area could be de-bushed per annum.

The impacts of de-bushing on the values of key ecosystem services (e.g. increased revenue from additional beef production) are then estimated, along with the direct costs of de-bushing operations, using real prices (base year 2015). However, under the Total Economic Valuation (TEV) framework

used, the investment that would be necessary to unlock the potential benefits (e.g. purchase of additional livestock) is not quantified.

It is estimated that de-bushing could generate benefits for livestock production, groundwater recharge, and tourism, as well as charcoal and firewood production and electricity generation. However, it would entail costs in the form of de-bushing operations, additional emissions from livestock, and loss of soil organic carbon.

The final step, cost-benefit analysis, uses these values to estimate the potential net benefits of a programme of de-bushing, compared with the BAU scenario of no de-bushing, over a 25-year time horizon. Annual costs and benefits are discounted by a real discount rate of 6% per annum. In the central case, the total benefits from ecosystem services as a result of de-bushing are estimated at N$76.1 billion (2015 prices, discounted) over 25 years, while the total costs are estimated at N$28.1 billion. This results in estimated net benefits of N$48.0 billion. In other words, if the investment required to unlock potential ecosystem service benefits is less than N$48.0 billion, de-bushing would generate a positive Net Present Value (NPV).

Scenario analysis indicates that the net benefits could range from N$24.9 billion, if the de-bushing rate is only 33% (rather than 67%) to N$111.9 billion in a best case scenario. At a de-bushing rate of 67%, net benefits under a worst case scenario are estimated at N$28.9 billion.

Partial sensitivity analysis is performed to ascertain how sensitive the central estimate of net benefits is to individual variables. Using the Social Cost of Carbon (SCC), rather than the Namibian offset value for carbon, results in an N$11.3 billion decrease in the estimated net benefit to N$36.8 billion. At the other end of the scale, assuming that groundwater recharge increases from the current 1% of rainfall to 3% (rather than 2%), the estimated net benefit more than doubles to N$100.9 billion. The net benefits are also observed at varying discount rates. At a discount rate of 12%, net benefits are estimated at N$18.5 billion, but at a rate of 4%, the net benefits are estimated at N$67.4 billion.

These results suggest that the net benefits of de-bushing would be significantly positive (in the total economic value sense). Hence, de-bushing could make a considerable contribution to Namibia's welfare. Furthermore, as we believe that many of the unquantified ecosystem services would be positively affected by de-bushing, it is reasonable to expect that there is upside risk to our estimates.

As this study is a TEV, the next step should be an analysis of the investment costs required to unlock the potential benefits. Further investigation into the sector-specific and location-specific costs and benefits is also recommended, as there are likely significant differences in the net benefits of de-bushing across sectors and regions. The sector-specific analysis should include a focus on the business cases for each initiative (e.g. increasing beef production, generating electricity from biomass). The required capital investment, as well as the value chains, should be costed, to ascertain which initiatives would offer the best return.

Further research is also recommended, focussing on the effects of de-bushing on ecosystem services that are currently unquantifiable or uncertain, the environmental impacts of de-bushing, and potential mitigation measures.

1 Introduction

1.1 Background

Bush encroachment in Namibia is a significant problem, affecting around 26 to 30 million hectares of land, or around a third of the country's land area (Honsbein et. al. 2009). Aside from the negative effects on agricultural productivity, bush encroachment also has significant impacts on ecosystems and their services. While the concerns over agricultural productivity are well recognised, the impacts on other ecosystem services are less well recognised but no less important. This importance is highlighted in the Namibian Government's Vision 2030, where Chapter 5 states:

> "The integrity of vital ecological processes, natural habitats and wild species throughout Namibia is maintained whilst significantly supporting national socio-economic development through sustainable low-impact, consumptive and non-consumptive uses, as well as providing diversity for rural and urban livelihoods."

This report therefore provides an initial broad basis to incorporate total economic valuation in assessing the costs of bush control and potential benefits that can be obtained from de-bushing.

1.2 Objectives

The key objectives of this study are:

- to provide initial economic valuations to guide policy development and processes
- to provide a framework that can be used and iterated upon when analysing particular policy options or actions to assess the most suitable approach to managing bush encroachment.

1.3 Structure

The report proceeds as follows:

- Section 2 provides a background to bush encroachment in Namibia and its effects;
- Section 3 presents the methodology that was followed;
  Section 4 discusses the delineation and assessment of bush encroachment;
- Section 5 identifies the ecosystem services impacted by bush encroachment and how they are affected;
- Section 6 offers a valuation of some key ecosystem services impacted by bush encroachment;
- Section 7 details the cost-benefit analysis and its outcomes;
- Section 8 provides policy recommendations; and
- Section 9 concludes.

2 Bush encroachment in Namibia

Bush encroachment is defined as "the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass:bush ratio, a decrease in biodiversity, and a decrease in carrying capacity" (De Klerk 2004). It affects an estimated 26 to 30 million hectares of land in Namibia, although this figure is currently under review.

There are many interlinked factors contributing to bush encroachment, but overgrazing is thought to be one of the key drivers. Overgrazing causes a decrease in the root base of grasses, reducing their competitiveness with regard to water and nutrient uptake and weakening their suppressive effect over emerging bushes. The additional water and nutrients left in the soil are then taken up by bushes, fuelling their growth at the expense of grass growth and recovery.

This can also happen when periods of drought, which reduce the grassy layer, are followed by periods of high rainfall – this creates very favourable conditions for woody plants to establish themselves in large numbers.

However, the relationship is complex and, depending on the area and nature of encroachment, other factors include:

- The displacement of browsers, such as kudu, by cattle or other grazing livestock, which puts extra pressure on the grassy component and relieves pressure on the woody plants which flourish
- Increased CO_2 concentrations in the atmosphere may also be encouraging the growth of woody species over grasses
- Rainfall – greater rainfall is associated with higher densities of bush
- The suppression of high-intensity fires, due to cattle farming, which would otherwise kill the seedlings and saplings of woody species.

Whatever the underlying causes, the phenomenon of bush encroachment certainly impacts on ecosystem services and biodiversity, as discussed in Section 5. In particular, it is thought that some services that are of significant value to Namibia, such as livestock production, groundwater recharge, tourism, and biodiversity, are negatively affected. This has given rise to calls for an extensive programme of de-bushing, to reduce bush encroachment and try to reverse some of these negative impacts.

De-bushing is generally carried out by mechanical or chemical means. The direct, environmental, and social costs are discussed and, where possible, quantified in Section 6.5. De-bushing is expected to improve services such as livestock production, groundwater recharge, tourism, and biodiversity, as well as providing biomass for electricity production, firewood, and charcoal production, as well as construction materials and crafts (discussed in Section 6).

However, de-bushing is also likely to have some negative effects and resultant environmental costs. Mechanical means of de-bushing can disrupt the soil and non-encroacher vegetation while chemical means have the potential to poison non-target vegetation and water sources. As bushes are a carbon sink, de-bushing will decrease the amount of carbon sequestered in the soil as well as in the woody component. Furthermore, if cattle stocks are increased in response to de-bushing, this would increase greenhouse gas emissions.

Figure 2.1 illustrates the ten bush-encroached zones originally identified by Bester (1999) and reassessed by Honsbein et. al. (2009); these are defined by location and average density, and specify the dominant species. Table 2.1 presents more detailed data on the area of communal and commercial farmland affected in each of the ten bush-encroached zones. Around 60% of bush-encroached land is commercial while the remaining 40% is communal. As it is thought that the land affected in Zone 10 has little commercial use, we have assumed that de-bushing would not be carried out here, and have instead focussed on the costs and benefits that would arise from de-bushing operations in Zones 1 to 9.

Figure 2.1: Bush encroached areas and bush density in Namibia

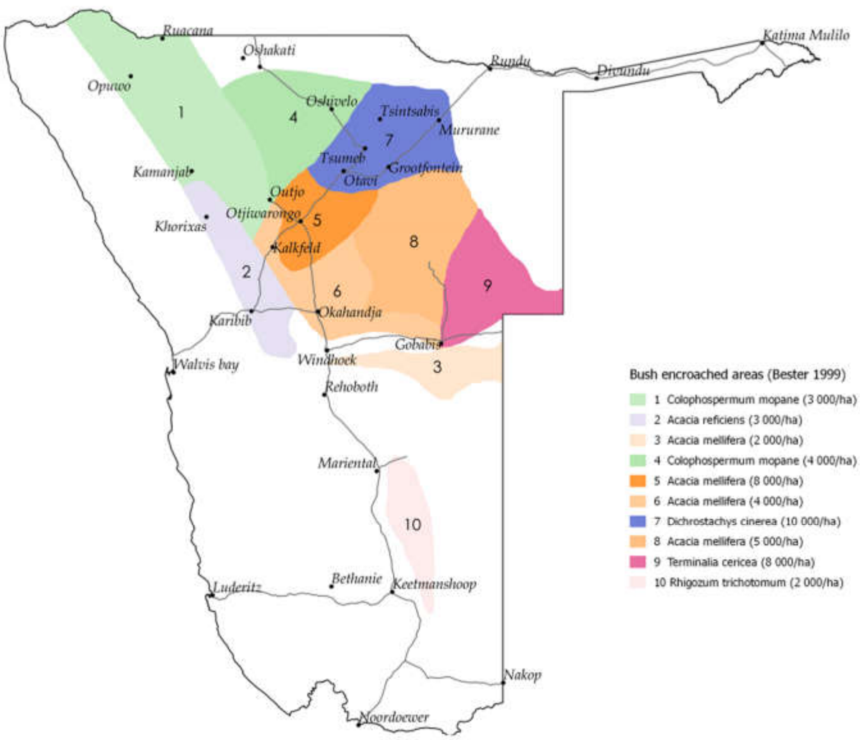


Table 2.1: Approximate area covered by different dominant bush species in commercial and communal agricultural areas

Category of thickened bush			Affected land (hectares)		
No. of area (map)	**Main bush species**	**Bush density (avg. no. / ha)**	**Commercial land**	**Communal land**	**Total**
1	Colophospermum mopane	2,500	1,451,000	2,986,000	4,437,000
2	Acacia reficiens	3,000	1,676,000	691,000	2,367,000
3	Acacia mellifera subsp. detine	2,000	3,360,000	195,000	3,555,000
4	Colophospermum mopane	4,000	482,000	1,090,000	1,572,000
5	Acacia mellifera subsp. detine	8,000	2,067,000	13,000	2,080,000
6	Acacia mellifera subsp. detine	4,000	2,692,000	210,000	2,902,000
7	Dichrostachys cinerea	10,000	2,513,000	1,220,000	3,733,000
8	Acacia mellifera subsp. detine	5,000	950,000	2,453,000	3,403,000
9	Termalia sericea	8,000	586,000	1,624,000	2,210,000
10	Rhigozum trichotomum	2,000	No mentionable commercial use		
Total			**15,777,000**	**10,482,000**	**26,259,000**

Source: Honsbein, Peacocke, & Joubert 2009

3 Methodology

The methodology used in this report broadly follows the 6+1 step approach of the Economics of Land Degradation (ELD) Initiative, which establishes a common methodological approach for establishing a robust cost-benefit analysis to inform decision-making processes. Some changes have been adopted in response to known data availability and other environmental economic approaches being promoted in Namibia (see Figure 3.1). These variations from the general ELD approach should not impact the validity of the final product and if anything should further enhance the outcomes as being consistent with and relevant to the other environmental economics processes underway in Namibia.

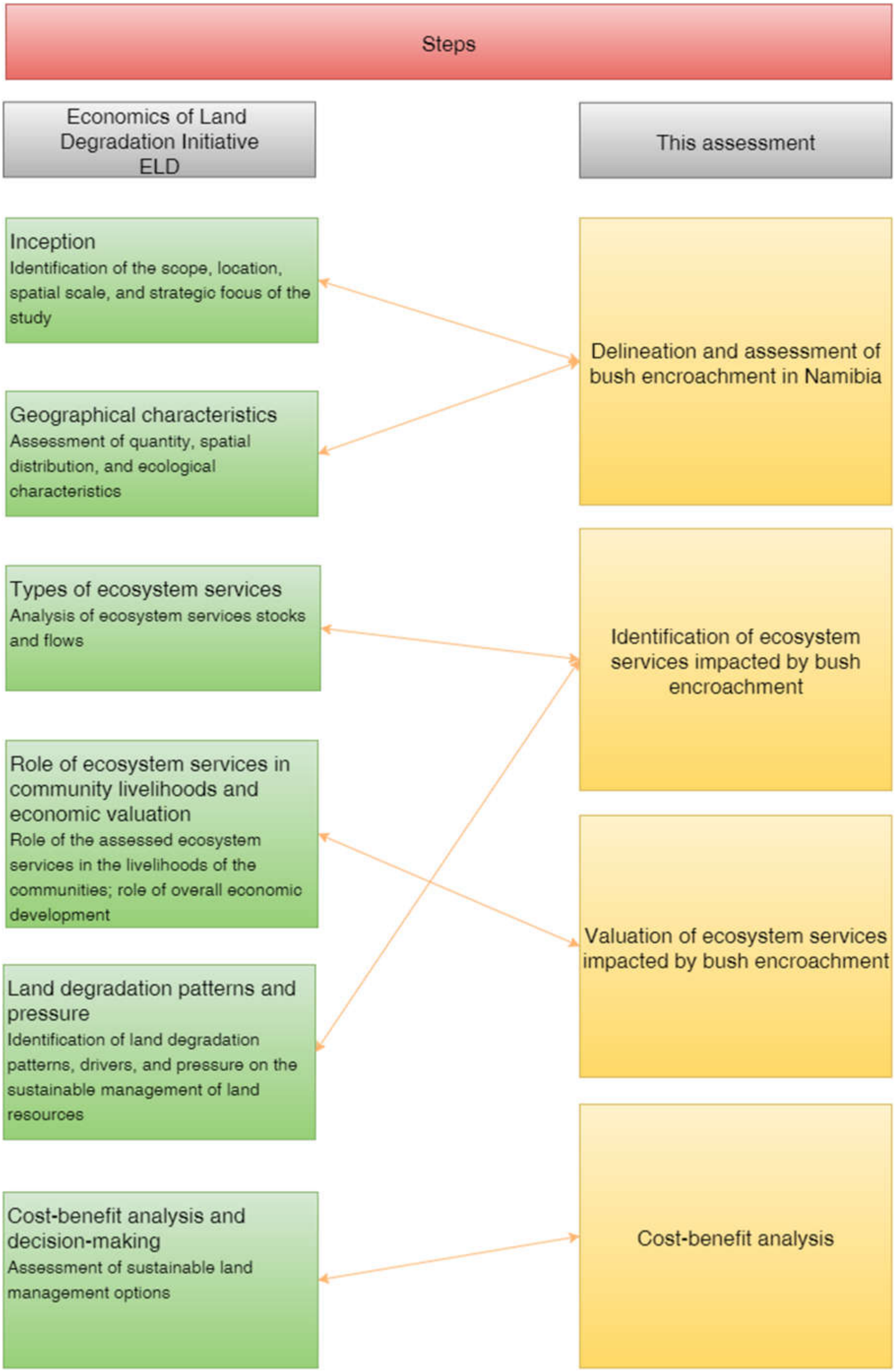
Limitations on the available data have prevented the analysis and valuation of several ecosystem services affected by bush encroachment and de-bushing. This report attempts to develop a framework in which these gaps and limitations can be highlighted and addressed through further work. This includes further natural resource economics work undertaken by the Ministry of Environment and Tourism (MET), with the Resource Mobilisation (ResMob) project, the ongoing work by the Ministry of Land Reform (MLR) in developing Integrated Regional Land-use Plans, the Land Degradation Neutrality (LDN) championed by the Sustainable Land Management Committee, and of course this project, all supported by the GIZ.

3.1 Delineation and assessment of bush encroachment in Namibia

This step effectively combines steps 1 and 2 of the ELD approach (see Section 4).

As bush encroachment only affects certain areas of Namibia, bush-encroached zones were mapped out in relation to ecological, social, utilisation, and political parameters, using GIS software. This spatial visualisation allowed for an analysis of existing data to determine the extent and symptoms of bush encroachment in relation to these key parameters.

Figure 3.1: Methodology for the ELD Initiative and this study

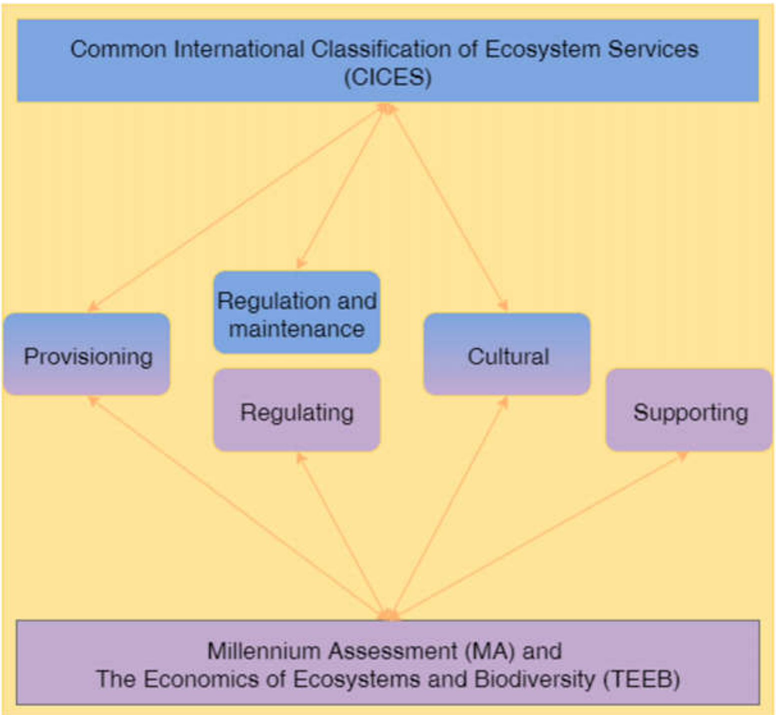


3.2 Identification of ecosystem services impacted by bush encroachment

This step effectively combines steps 3 and 5 of the ELD approach (see Section 5).

A literature review was conducted and expert knowledge used to understand the key types of ecosystem services affected by bush encroachment and assess the positive and negative impacts of bush encroachment and de-bushing across a range of these ecosystem services. This report adopts the Common International Classification of Ecosystem Services (CICES) classification (see Appendix I) in order to remain consistent with the draft Inventory of Ecosystem Services in Namibia (2015) and also the UN System of Environmental-Economic Accounting: Experimental Ecosystem Accounting (SEEA-EEA, 2014), which is being promoted by the MET-GIZ ResMob project in Namibia. The CICES classification recognises three categories of services: provisioning, regulation and maintenance, and cultural. This differs from the ELD Initiative which uses the Millennium Assessment (MA) and The Economics of Ecosystems and Biodiversity (TEEB) approach of recognising four categories of services: provisioning, regulating, cultural, and supporting.

Figure 3.2: Classification of ecosystem services – CICES, MA, and TEEB



3.3 Valuation of ecosystem services impacted by bush encroachment

This step is effectively step 4 of the ELD approach (see Section 6).

Where possible, the key ecosystem services affected by bush encroachment and de-bushing were quantified and valued. Monetary values were generated for livestock production, groundwater recharge, carbon sequestration, and a number of uses of the biomass for energy. The costs of de-bushing were also estimated. However, many impacted ecosystem services were unable to be valued due to a lack of data and research.

Table 5.1, Table 5.2, and Table 5.3 present our assessments of the likely direction of change in ecosystem service values due to de-bushing. We believe that a large number of ecosystem services would benefit from de-bushing, which suggests that there is upside risk to our estimate of net benefits.

The valuation framework focussed on market values, as most of the valued services were provisioning services. An avoided cost approach was taken for groundwater recharge, as well as a price-based approach using bulk water tariffs, although water tariffs are not a true reflection of the value of water. Changes in carbon sequestered were valued using an estimate for the offset value in Namibia (in the absence of a market) as well as the Social Cost of Carbon (SCC). Please see Section 6 for more detail.

The Total Economic Valuation (TEV) framework used in this report attempts to value the potential costs and benefits for ecosystem services that could arise following a de-bushing exercise (e.g. a rise in livestock production via increased carrying capacity) as well as the direct costs of de-bushing operations.

3.3.1 Key assumptions

Below are listed some key assumptions for this study, which are consistently held throughout the analysis.

- ***60%* of the identified bush-encroached land to be de-bushed**
  Of the 26.3 million hectares of bush-encroached land, it is assumed that 60% (15.8 million hectares) will be targeted for de-bushing. It is not specified which areas will be de-bushed and which will not, nor is the nature of the selection of actual bushes factored in. Some areas may not be de-bushed due to their remoteness, lack of economic incentives, or the potential damage that de-bushing may have on the environment (e.g. fragile soils).
- **Encroacher bush density to be reduced by *67%* in the central case and *33%* in a key alternate scenario**
  De Klerk (2004) suggests a rule of thumb for estimating optimal bush density:

  > "The number of tree equivalents per hectare should not exceed twice the long-term average rainfall (mm). A tree equivalent (TE) is defined as a tree (shrub) of 1.5 m in height. Thus, a 3-m shrub would represent 2 TE, a 4.5-m shrub 3 TE, etc. Land should, therefore, never be completely cleared."

  As the data on bush encroachment used in this study reports density in bushes per hectare without referring to bush size[1], we were unable to apply this relationship and instead relied on other relevant literature and anecdotal evidence. It was assumed that a 67% rate (two-thirds) of de-bushing (i.e. leaving 33% of the original bush untouched) would be a reasonable estimate. For example, Christian et. al. (2010) cite a study in which grass cover and carrying capacity almost doubled in response to a de-bushing rate of 67%. This rate of de-bushing was applied to all bush-encroached zones, no matter the density.

[1] If data is produced for bush size as well as density and coverage, the above formula should be used to generate more accurate estimates of optimal bush density.

However, Smit et. al. (2015) suggest that only 30-35% of total available biomass should be harvested. We assume that the harvest proportion would be equal to the de-bushed proportion, so a 33% rate of de-bushing was taken as a key alternate scenario.

- ***5%* of the targeted bush-encroached land to be de-bushed per annum**
  This would be equivalent to 787,770 hectares being de-bushed per annum, which we believe is feasible. The initial round of de-bushing (i.e. disregarding any follow up or aftercare) would therefore be carried out over a period of 20 years, with the effects being captured over one 25 year period (see below).

3.4 Cost Benefit Analysis of Scenarios

This step is effectively step 6 of the ELD approach (see Section 7).

As discussed in Section 3.3, key ecosystem services were valued under a business-as-usual (BAU) scenario (i.e. the current degree of bush encroachment) and under a scenario of de-bushing (with the assumptions above). The net benefit of de-bushing was calculated as the difference between the two scenarios – de-bushing and no de-bushing.

Further assumptions and decisions had to be made for the cost-benefit analysis.

3.4.1 Time horizon

A time horizon of 25 years was chosen. This captures the 20 years spent on the initial de-bushing (i.e. without follow ups or aftercare) and allows time for ecosystem services, such as livestock production and groundwater recharge, to reach their new potential.

3.4.2 Prices

Real prices in Namibian dollars (base year 2015) were used. Prices were generally held constant (in real terms) across the entire time horizon. The exception was the Social Cost of Carbon (SCC), which escalated each year, as it has been forecasted by the US government.

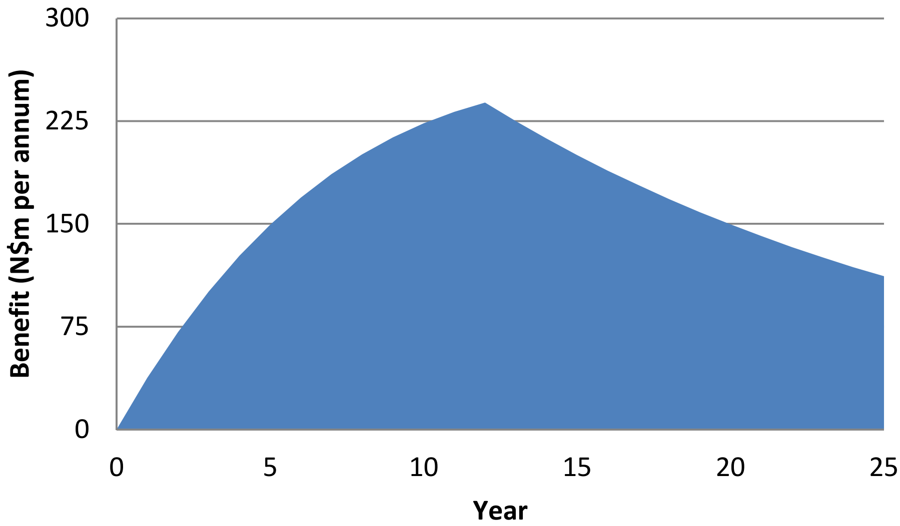
3.4.3 Discount rate

The costs and benefits calculated must be discounted because it is generally accepted that their values in the future are worth less than the same amount today. This reflects the opportunity cost of resources (i.e. money could be invested today to reap a return in the future) and people's time preference (the general preference is to consume resources sooner rather than later) (Boardman et. al., 2014).

As real prices were used in the calculations, a real discount rate had to be used (rather than a nominal rate). In the central case, a real discount rate of 6% per annum was used. This is based on the real discount rate used in the Wildlife Resource Accounts of Namibia, 2004 (2009).

Chart 3.1 (same as Chart 6.6) illustrates the effect of discounting. Although charcoal production plateaus at 300,000 additional tonnes from Year 12 until Year 25, the annual benefits decline over the same period. This is because the same real monetary benefits are valued less the further into the future they are.

Chart 3.1: Benefit of increased charcoal production



> **Example**
>
> If you were offered $100 today or $100 in one year's time, which would you take?
>
> If you took the $100 today and invested it in the bank at an interest rate of 10%, in one year's time you would have $110. So the **present value** of $110 in one year's time is $100.
>
> This is why we need to discount future values – so that we can compare intertemporal costs and benefits.

3.4.4 Sensitivity analysis

Sensitivity analysis involves changing key assumptions and variables to ascertain how they would affect the final outcome (see Section 7.1). One of the most important variables to undergo sensitivity analysis is the discount rate, as the choice of rate can be quite subjective and it can significantly impact the final outcome. In this case, net benefits tend to decrease as the discount rate rises because the benefits of de-bushing tend to be weighted towards the middle and end of the time horizon and are consequently more heavily discounted.

3.5 Key limitations

One of the key limitations of this study is the deficiency of data and knowledge on how ecosystem services are affected by bush encroachment and de-bushing. For example, the uncertainty regarding the impact on groundwater recharge rates is of particular concern as the estimated benefit from groundwater accounts for a huge proportion of the total benefits. As such, further research in this area would undoubtedly improve the accuracy of these estimates.

Furthermore, data on ecosystem service values, particularly in the Namibian context, is lacking, preventing many impacted services from being valued. Even a benefit transfer approach, drawing estimates from other studies, was constrained as there is very little research in the public domain on this subject. Specific data limitations and assumptions are detailed by ecosystem service in Sections 5 and 6.

A second limitation is that, by using a TEV framework, this study only values the costs and benefits for ecosystem services from de-bushing against the direct cost of de-bushing operations. It does not quantify the investment that would be necessary to unlock the potential ecosystem service benefits (e.g. purchase of additional livestock to utilise increased carrying capacity). Therefore, it does not reflect the total costs that would need to be outlaid.

This means that the net benefit estimated in this report (N$48.0 billion) would be lower once investment costs are taken into account. Essentially, if the investment required to unlock potential ecosystem service benefits is less than N$48.0 billion, de-bushing would generate a positive NPV.

Investment costs would vary significantly by sector, requiring sector-specific analysis with a focus on the business cases for each initiative. For livestock production, investment costs would include the purchase of additional livestock, feed, fences, and labour to manage the stock. For tourism, accommodation, vehicles, the purchase of wildlife stock, extra staff would be major costs.

With regard to groundwater, it should be noted that our estimate of benefits from de-bushing reflects the value of the volume of additional groundwater that would be recharged across the entire de-bushed area of Namibia, rather than the additional groundwater that would be accessible using current infrastructure. It does not take into account the investments in infrastructure, equipment, and staff that would be required to enable extraction of the additional volume. Some of this additional recharge would not be possible to extract at all, if it is too deep or too scattered into micro aquifers to retrieve cost-effectively.

For value added industries, such as charcoal production and electricity generation, investments in plants and buildings, machinery and equipment, and labour would be necessary. These costs would be particularly significant in determining which industry would offer the greatest return for their "biomass" product or service.

4 Delineation and assessment of bush encroachment in Namibia

Bush encroachment is present in most regions of Namibia, affecting multiple ecosystems and land uses. This makes it a complex problem, as impacts can vary depending on the surrounding environment (e.g. types of soil, other vegetation, wildlife), how the land is and could be used (e.g. cattle farming, tourism), and how many people depend on the land. Furthermore, the appropriate method, range, and scope of de-bushing activities are also dependent on the local context. For example:

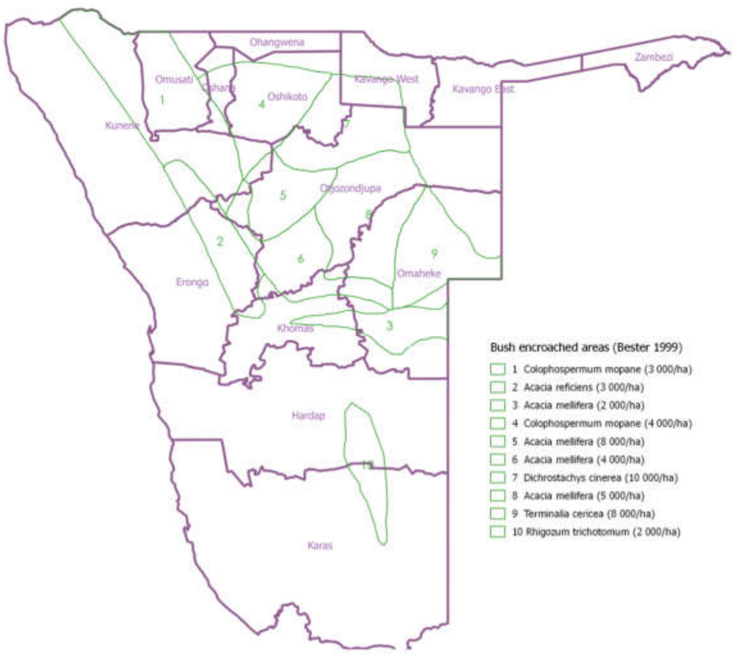
- large-scale mechanical harvesting methods would likely degrade more arid, fragile soils, where small-scale methods would be more suitable
- arboricides may have detrimental effects when used on sandier soils, where the chemicals can be more mobile and be transmitted to non-encroacher bushes and trees or pollute water bodies
- harvesting may not be feasible in the more remote areas.

4.1 Political regions

Figure 4.1 illustrates the range and density of bush encroachment across the political regions of Namibia. Bush encroachment affects eleven of the fourteen regions in Namibia, but the densest encroacher bush can be found in Otjozondjupa, Oshikoto, Kavango West, and northern Omaheke. Bush tends to be sparser in the drier regions, such as Hardap, Karas, Kunene, Erongo, Khomas, and southern Omaheke.

Bush encroachment affects the greatest area of farmland (both commercial and communal) in zone 1, across Kunene and Omusati (see Table 2.1), at almost 4.5 million hectares. Swathes of farmland across Otjozondjupa, Oshikoto, Kavango West, and Omaheke are also affected.

Figure 4.1: Bush encroachment and political regions in Namibia

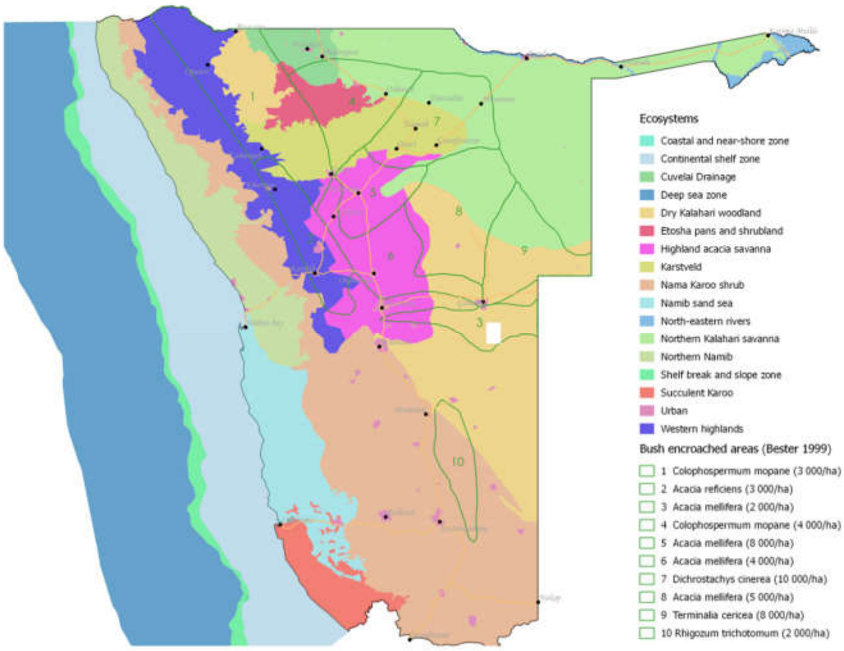


4.2 Ecosystems

Bush encroachment affects multiple ecosystems in Namibia. Figure 4.2 shows that it is present across large expanses of the Highland acacia savanna, Etosha pans and shrubland, and Karstveld. It is also a problem in some areas of the Western highlands, Dry Kalahari woodland, Northern Kalahari savanna, Nama Karoo shrub, and Cuvelai Drainage.

The draft Inventory of Ecosystem Services (2015) was referred to in establishing the presence and influence of bush encroachment in each of the identified ecosystems in Namibia. In all these ecosystems, the effects of climate change may be realised through increased rates of bush encroachment as a result of increased carbon dioxide concentrations, but there is considerable uncertainty around this.

Figure 4.2: Bush encroachment and ecosystems in Namibia



4.2.1 Highland Acacia Savanna

Overgrazing has reduced grass cover and available pasture and fire control and prevention measures have reduced the frequency and intensity of bush fires in this ecosystem. This, in turn, has led to increased bush encroachment, which would otherwise be moderated by hot fires killing off small bushes, further reducing available pasture. The conversion of farms into resettlement farms has also affected the use of the land, the availability of pasture and the incidence of overgrazing, and may limit incentives and capacity to invest in measures to combat bush encroachment.

The reduced grass cover has led to increased surface runoff, and after heavy rains runoff can be particularly rapid and result in soil erosion. Conversely, slower flows that had been sustained by seepage have declined because of reduced rainfall infiltration.

This ecosystem typically experiences moderate encroachment densities of around 3000-4000 bushes per hectare.

4.2.2 Etosha Pans and Shrublands

On communal land in the north of the ecosystem, there have been large increases in cattle numbers. This, and the expropriation of communal land into (effectively) private land, has resulted in overgrazing. As in other zones (such as the Kalahari Woodlands and the Highland Acacia Savanna) this has led to a reduction in fire and consequently increased rates of bush encroachment.

This ecosystem typically experiences moderate encroachment densities of around 3000-4000 bushes per hectare.

4.2.3 Karstveld

As in the Highland Acacia Savanna zone, overgrazing and fire control and prevention measures have led to increased bush encroachment. This, is turn, has resulted in increased surface runoff and soil erosion in some areas, and reduced groundwater recharge. The conversion of farms into resettlement farms may limit incentives to invest in measures to combat bush encroachment..

This ecosystem typically system experiences moderate to densities of 3,000-4,000 bushes per hectare in the west and very high densities in the east of 10,000 bushes per hectare.

4.2.4 Western Highlands

As in many of the ecosystems described in this section, overgrazing is a significant issue, which has led to bush encroachment, land degradation, and a reduction in the productivity of pastures. However, the impact has not been as severe in this zone, with average densities estimated at around 3,000 bushes per hectare.

4.2.5 Dry Kalahari Woodlands

As in the Highland Acacia Savanna, Karstveld, and Northern Kalahari Woodlands, habitat change has occurred primarily as a result of overgrazing, driving bush encroachment and impacting services such as groundwater recharge.

This ecosystem typically experiences moderate to high encroachment densities of around 3,000-8,000 bushes per hectare in its northern half.

4.2.6 Northern Kalahari Woodlands

This zone experiences the same drivers of and results from bush encroachment as the Highland Acacia Savanna, Karstveld, and Dry Kalahari Woodlands.

This ecosystem typically experiences high encroachment densities of around 5,000-10,000 bushes per hectare in its western half.

4.2.7 Nama Karoo Shrublands

Overgrazing has given rise to bush encroachment (in particular of *Rhigozum* and *A.nebrownii*), resulting in a gradual decline in rangeland productivity and reduced groundwater recharge rates.

This ecosystem typically experiences low encroachment densities in an area focussed around Mariental of approximately 2,000 bushes per hectare.

4.2.8 Cuvelai Drainage

As in many other ecosystems across Namibia, overgrazing is a particular pressure, promoting bush encroachment, and contributing to soil erosion and reduced groundwater recharge.

This ecosystem typically experiences moderate encroachment densities of around 4,000 bushes per hectare in its southern portion.

4.3 Land use

Bush encroachment is overwhelmingly a problem for commercial agriculture and communal agriculture, both large- and small-scale (see Figure 4.3). It also impacts tourism, such as game viewing and hunting, and affects some state-protected areas, most notably, Etosha National Park.

4.3.1 Livestock farming

In terms of agriculture, bush encroachment mainly affects livestock farming (cultivation generally requires that the land is cleared, whether bush encroached or not). As discussed in Section 4.2, overgrazing, particularly by cattle, is a key contributor to bush encroachment, so it comes as no surprise that bush encroachment is concentrated in areas of livestock farming.

Bush encroachment reduces available pasture land for livestock, particularly cattle, but also sheep and other livestock. It does this by restricting access for livestock and by reducing grass cover used for feed. There is a vicious cycle of reduced grass cover resulting in greater pressure on remaining grass cover, contributing to higher encroachment rates and further reducing grass cover.

Livestock carrying capacities have been drastically reduced (see Section 4.4) to the detriment of farmer incomes and profits. This has also compromised food security and nutrition, particularly in communal areas.

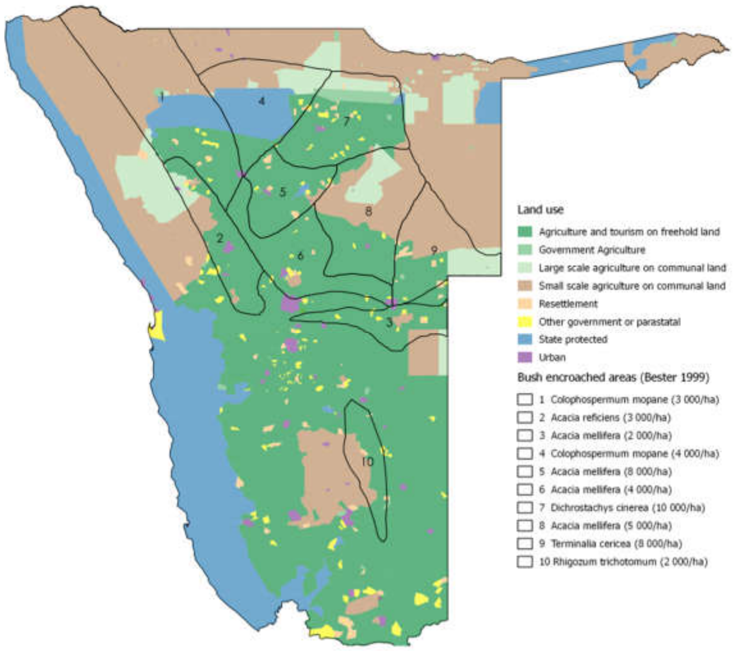
4.3.2 Game farming

Bush encroachment's net impact on game farming is less clear-cut. On the downside, it may reduce available land for wildlife, but there could be a positive effect if some farmers replace cattle and other domesticated animals with game. It is therefore difficult to assess whether bush encroachment results in a net gain or loss of outputs such as game meat and skins. Furthermore, browsers (e.g. goats, kudu, eland, dik dik, black rhino) can actually benefit from a certain degree of bush encroachment, which expands their food source. However, if bush is too dense and dominant, this could disadvantage browsers by restricting movement and access and reducing the variety of their food.

4.3.3 Tourism

Tourism operators have also been affected as dense bush can undermine wildlife viewing, hunting, other activities such as hiking, and landscape appreciation by reducing the opportunity and success rates for viewing or hunting, decreasing the diversity of species, and reducing the enjoyment that individuals gain from viewing wide, open landscapes which are symbolic of Namibia. This may result in fewer visitors, lower satisfaction levels, and less revenue. However, the relationship between bush encroachment and tourism-centric activities is quite tenuous, and it is difficult to isolate the net impact of de-bushing on these services.

Figure 4.3: Bush encroachment and land use in Namibia

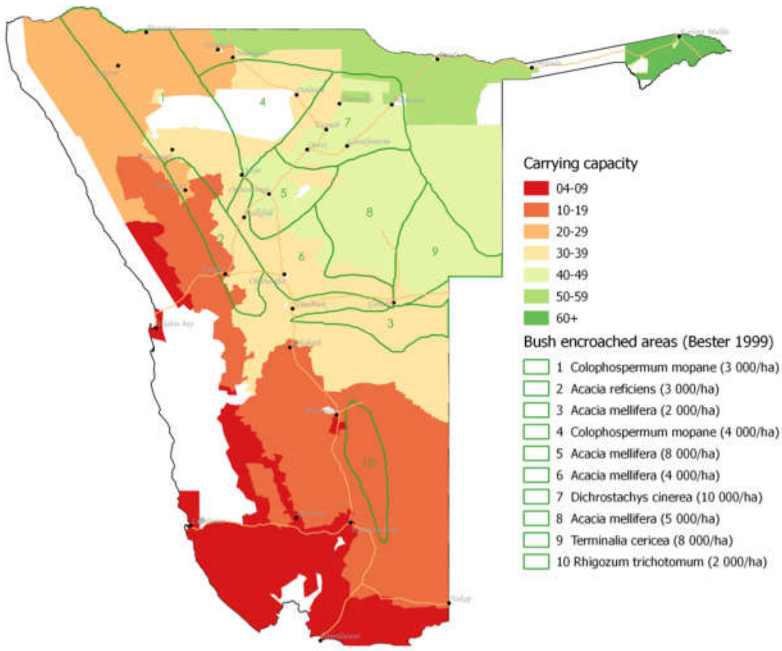


4.4 Livestock carrying capacity

Figure 4.4 shows the estimated livestock carrying capacity under optimal rangeland conditions (i.e. without bush encroachment). It is estimated that bush encroachment has, on average, reduced these carrying capacities (in kilograms lives weight per hectare) by at least half, to the detriment of farmer incomes and profits. This has also compromised food security and nutrition, particularly in communal areas. Cattle farming, in particular, is a traditional way of life for many peoples in Namibia. In addition to its economic value, it has cultural, heritage, and symbolic value. These values have all been undermined by bush encroachment.

However, it must be noted that overgrazing, particularly by cattle, is a key contributor to bush encroachment. Therefore, if a de-bushing programme is implemented, good rangeland management practices must be followed to prevent future bush encroachment. This may mean that stocks should not be built back up to the numbers seen prior to significant bush encroachment.

Figure 4.4: Bush encroachment and livestock carrying capacity in Namibia



4.5 Rainfall

As would be expected, bush density tends to be higher in areas of greater average rainfall (see Figure 4.5). Higher volumes of water available for uptake by bushes support greater numbers and growth, particularly when grasses have been compromised by overgrazing and drought.

In the southern and western regions of the country, bush encroachment does not appear to be a significant problem, but moving north-east (in the direction of increasing rainfall), bush densities tend to increase. Zone 7 has the highest average rainfall of the ten bush-encroached zones and is also estimated to have the highest bush density of 10,000 bushes per hectare. The four zones with the lowest densities (1, 2, 3, and 10) also experience the lowest average rainfall (325mm or less).

Chart 4.1 illustrates this positive correlation between rainfall and bush density.

Figure 4.5: Bush encroachment and rainfall in Namibia

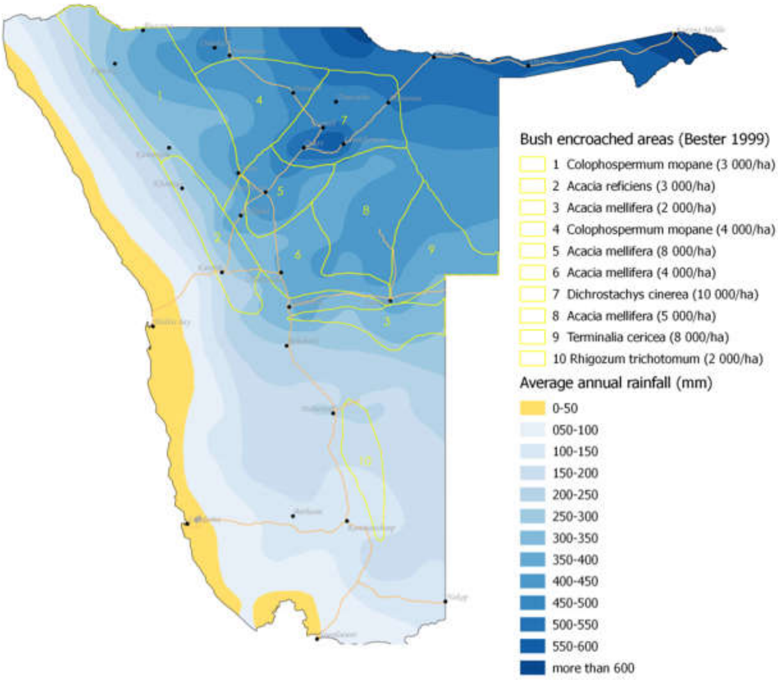
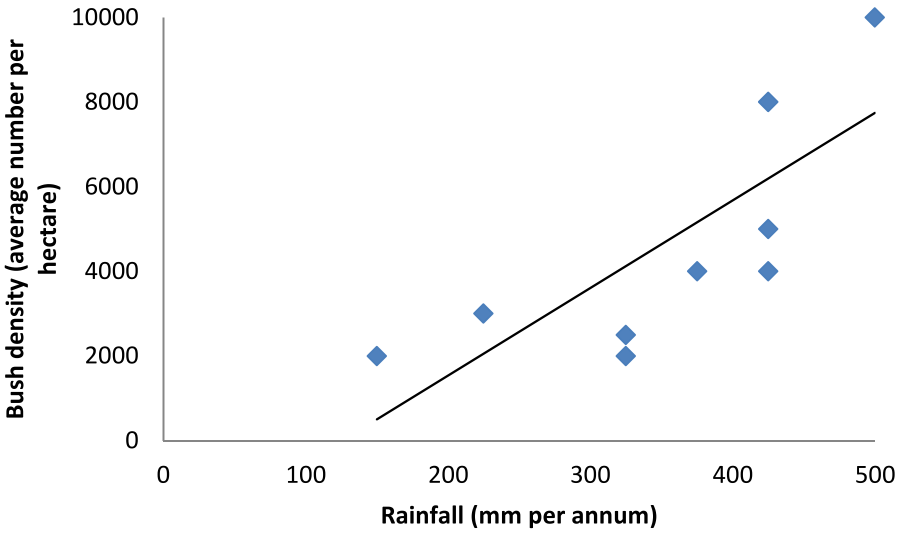


Chart 4.1: Rainfall and bush density



5 Identification of ecosystem services impacted by bush encroachment

This section reviews the potential impacts of bush encroachment on ecosystems and their services. This report adopts the Common International Classification of Ecosystem Services (CICES) classification (see Appendix I) in order to remain consistent with the draft Inventory of Ecosystem Services in Namibia (2015) and also the UN System of Environmental-Economic Accounting: Experimental Ecosystem Accounting (SEEA-EEA, 2014), which is being promoted by the MET-GIZ ResMob project in Namibia. The CICES classification recognises three categories of services: provisioning, regulation and maintenance, and cultural.

Bush encroachment is manifested largely through habitat change. As discussed in Section 2, overgrazing, the suppression of fires, and the displacement of browsers, all largely due to livestock farming, are key drivers of bush encroachment. Furthermore, climate change could be exacerbating bush encroachment via increased concentrations of carbon dioxide in the atmosphere, but there is significant uncertainty surrounding this.

The following tables outline the relevance of each ecosystem service to bush encroachment and the likely direction of change in the service due to de-bushing. For many ecosystem services, there is little data or research on how they might be impacted by de-bushing. A more detailed discussion on the expected changes and how these may be valued can be found in Appendix II.

5.1 Provisioning

Provisioning services are "all nutritional, material and energetic outputs from living systems" (Haines-Young and Potschin 2013).

Table 5.1: Provisioning ecosystem services – impacts of de-bushing

Relevance	Ecosystem service class	Example	Estimated direction of impact from de-bushing	Notes
High	Reared animals and their outputs	Beef production	+	See Section 6.1
High	Groundwater for drinking and non-drinking uses	Drinking water, non-drinking water	+	See Section 6.26.1
High	Plant-based resources	Charcoal and firewood production, electricity generation	+	See Section 6.3
Medium	Cultivated crops	Maize, vegetables, sorghum etc.	+	Only relevant over a limited area. Would require complete clearing. Crop farming on de-bushed land could reduce valuation of meat production.

Medium	Wild plants, algae and their outputs	INPs (e.g. Devil's Claw)	+	But likely only up to a point, after which the impact may be negative. Only relevant over a limited area. Valuation requires further research.
High	Wild animals and their outputs	Game meat, skins	+/-	Depends on species and whether there is a move towards conversion to wildlife-based land uses. Further data required.
Medium	Surface water for drinking and non-drinking uses	Drinking water, non-drinking water (e.g. domestic use)	+/-	Depends on use of de-bushed land. Valuation requires further research.
High	Fibres and other materials for direct use or processing	Materials for construction	+	Depends on use of material after de-bushing. Requires further data.
High	Materials for agricultural use	Animal feed supplement	+/-	De-bushing yields material to be used in feed supplement, but depletes the overall supply. More data needed on other inputs and extent of use.
Low/none	Animal-based resources	Energy production from fat etc.	+	Only limited relevance, significant lack of data.

5.2 Regulation and Maintenance

Regulation and maintenance services "cover all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance" (Haines-Young and Potschin 2013).

Table 5.2: Regulation and maintenance ecosystem services – impacts of de-bushing

Relevance	Ecosystem service class	Example	Estimated direction of impact from de-bushing	Notes
High	Global climate regulation by reduction of greenhouse gas concentrations	Carbon sequestration	-	See Section 6.4
Unknown	Bio-remediation by micro-organisms, algae, plants and animals	Detoxification, decomposition and mineralisation.	Unknown	Needs further research.
Unknown	Filtration / sequestration / storage / accumulation by micro-organisms, algae, plants and animals	Filtration and sequestration of pollutants in soil.	Unknown	Needs further research. May depend on how bush is cleared, and what the alternative use of the land would be.

Unknown	Filtration / sequestration / storage / accumulation by ecosystems	Filtration / sequestration / accumulation by ecosystems	Unknown	Needs further research.
Unknown	Dilution by atmosphere, freshwater and marine ecosystems	Dilution by atmosphere / freshwater systems	Unknown	Needs further research
Low/none	Mediation of smell/noise/visual impacts	Screening of transport corridors	-	Impact depends on location and population density. Valuation requires further research.
High	Mass stabilisation and control of erosion rates	Control of soil erosion	+	Depends on the method of de-bushing. If positive impact, improved overall soil quality captures to large extent in meat production from livestock farming.
High	Buffering and attenuation of mass flows	Buffering of mass flows	+	Impact depends on location and nearby population and uses of the land. Avoided damages may be option for valuation if relevant. Needs further research
High	Hydrological cycle and water flow maintenance	Groundwater recharge	+	Primarily captured by the valuation for groundwater recharge.
Low/none	Flood protection	Flood protection along rivers	-	Location dependent. Needs further research. Avoided damages may be option for valuation.
Medium	Ventilation and transpiration	Ventilation and transpiration	-	Needs further research. Location dependent, as varies with local populations.
Low/none	Pollination and seed dispersal	Pollination	+/-	Needs further research. Location dependent. Interactions with other services relating to crops and livestock.
High	Maintaining nursery populations and habitats	Habitats for species	+/-	May be conflicting impacts based on species. Value could be reflected in part by tourism services (experiential and physical use), and other cultural services (e.g. bequest and existence).
Unknown	Pest control	Pest control	Unknown	Further research needed.
Unknown	Disease control	Disease control	Unknown	Further research needed.
High	Weathering Processes	Restoration of soils	+	Impact of soil and grassland restoration largely captured by valuation of meat production.

High	Decomposition and fixing processes	Nitrogen fixing and nutrient replenishment	+/-	Depends on species of bush and extent of de-bushing. Potential positive impacts largely captured by valuation of meat production.
Medium	Chemical condition of freshwaters	Condition of water in rivers and dams	+/-	Depends on location and use of land after de-bushing. Some overlap with provisioning services relating to surface water.
Unknown	Micro and regional climate regulation	Local climate, air quality, regional precipitation	Unknown	Further research needed.

5.3 Cultural

Cultural services "cover all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people" (Haines-Young and Potschin 2013).

Table 5.3: Cultural ecosystem services – impacts of de-bushing

Relevance	Ecosystem service class	Example	Estimated direction of impact from de-bushing	Notes
High	Experiential use of plants, animals & landscapes	Wildlife viewing	+	Valuation requires further research regarding the impact of de-bushing.
High	Physical use	Trophy hunting	+	Valuation requires further research regarding the impact of de-bushing. Rough estimate of scale of potential benefits presented in Section 6.5.
Medium	Scientific	Scientific research	+/-	Limited impact. Change in land cover restricts some potential for scientific research and increases others.
Medium	Educational	Education	+/-	Similar to scientific research
Medium	Heritage, Cultural	Ways of life	+/-	May relate to how land is used after de-bushing and presence of local populations. Require further research for valuation.
Low/none	Entertainment	Ex-situ viewing of wildlife / landscapes	+	Likely limited impact. Valuation requires further research.
Medium	Aesthetic	Aesthetic appreciation of landscape	+	Valuation requires further research.

Medium	Symbolic	Symbolic identification of landscape features	+	Valuation requires further research.
Unknown	Sacred and/or religious	Scared practices of communities	Unknown	Valuation requires further research.
Medium	Existence	Existence value to current generations	+	Valuation requires further research. Interactions with other services related to wildlife populations.
Medium	Bequest	Bequest value to future generations	+	Valuation requires further research. Interactions with other services related to wildlife populations.

5.4 Biodiversity

Biodiversity is not explicitly categorised as an ecosystem service, but it has a strong correlation with many ecosystem services. Diversity in animals, plants, and soil organisms can improve water and soil quality, increase the yield of several services (such as crop production), reduce yield variance, and improve resilience of ecosystems and their services to negative outside impacts. It can boost tourism and other cultural services and improve regulation and maintenance services. As such, many of the values of biodiversity are captured in the values of ecosystem services. Bush encroachment is believed to have a negative impact on biodiversity, as the rangelands deviate from the optimal mix of vegetation and alter the natural balance of wildlife. De-bushing, up to a point, is therefore believed to have a positive impact on biodiversity, if managed correctly.

6 Valuation of key ecosystem services impacted by bush encroachment

6.1 Livestock

In order to estimate the cost/benefit of the change in livestock production due to de-bushing (compared with no de-bushing), a two-step process was undertaken. The first step was to estimate the change in livestock numbers (Section 6.1.1) while the second step was to estimate the monetary value of this change (Section 6.1.2).

This study focusses on beef production because it is the dominant livestock production system in the bush-encroached zones. Further analysis could take into account dairy production, and the production of meat and other products, such as wool, from livestock other than cattle, but we believe that the majority of benefits would come from increased beef production.

6.1.1 Estimating additional cattle from increased carrying capacity due to de-bushing

Based on literature reviews and expert knowledge, the accepted rule of thumb is that a reduction in bush density to an optimal rate (here assumed to be 33% of current density, i.e. a reduction of 67%) would at least double carrying capacity. Therefore, we have assumed a doubling of cattle numbers in de-bushed zones from the current levels once the initial round of de-bushing is complete.

Livestock census data[2] were used to estimate head of cattle in each of the ten bush-encroached areas. The latest data available were for 2014 so it was assumed that numbers would be unchanged in 2015. These estimates of head of cattle were then split by land use (commercial and communal), assuming that cattle numbers were proportionate to the areas of commercial and communal land in each of the bush-encroached areas, as shown in Table 6.1.

Table 6.1: Cattle numbers from 2014 livestock census

No. of area (map)[1]	Head of cattle		
	Commercial land	Communal land	Total
1	50,750	104,439	155,189
2	49,230	20,297	69,527
3	37,445	2,173	39,618
4	30,120	68,114	98,234
5	108,333	681	109,014
6	94,879	7,401	102,280
7	90,479	43,925	134,405
8	28,039	72,399	100,438
9	11,539	31,978	43,516
10	n/a	n/a	n/a
Total	**500,813**	**351,408**	**852,221**

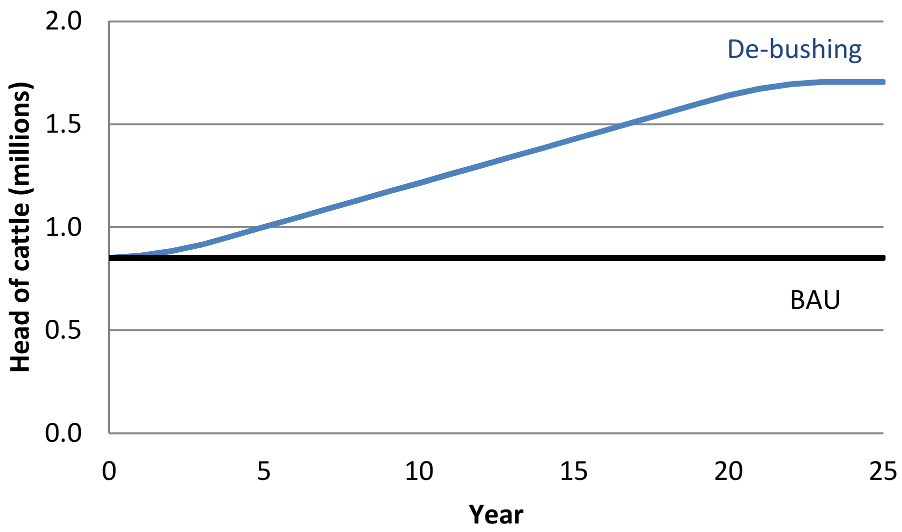
Source: Directorate of Veterinary Services 2014

1: Numbered bush-encroached zone (see Figure 2.1)

[2] Directorate of Veterinary Services

It was assumed that following de-bushing of an area to 33% of the current density, it would take four years for carrying capacity to double in that area. This was based on the personal experience of Hendrik Botha, a farmer in the Okahandja area, as presented during the Namibian Rangeland Forum (NRF) meeting in September 2015. Consequently, there is a lag in the escalation of cattle over the time horizon. Based on our estimates, carrying capacity for the entire bush-encroached area of Namibia would have doubled by the end of Year 23 (see Chart 6.1). It is implicitly assumed that the current carrying capacity is being fully utilised[3].

Chart 6.1: Head of cattle – de-bushing versus BAU



Offtake rates by land use and region (see Table 6.2) were used to estimate the number of cattle slaughtered. A conversion factor of 246.9kg/head[4] was then applied to estimate meat production in kilograms.

Table 6.2: Off-take rates 2015

Land use/region	Offtake rates (%)	Average (%)
Commercial	25-30	27.5
Communal (S of fence)	15-17	16.0
Communal (N of fence)	3-5	4.0

Source: Meat Board of Namibia

6.1.2 Valuing the increase in cattle

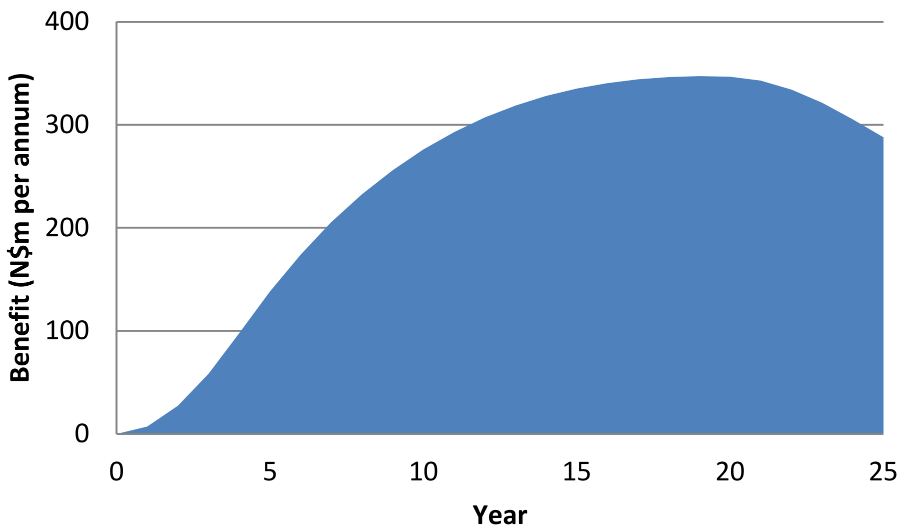
The year average beef producer price for 2015[5] of N$27.3/kg[6] was applied to the offtake to estimate revenue for commercial and communal farmers in the ten bush encroached areas. This was then summed to arrive at total revenue.

[3] This was confirmed as a reasonable assumption by Roelie Venter from the Namibia Agricultural Union (NAU)
[4] Namibian meat production data from the UN Food and Agriculture Organisation (FAO)
[5] Year to August 2015 – latest available data
[6] Meat Board of Namibia

A BAU scenario for no de-bushing was also set up under which cattle numbers remained constant. The difference between the total revenue obtained in each of these two scenarios represents the benefits that would be gained from increased beef production due to de-bushing.

The discounted benefit was estimated at **N$6.4 billion** over the 25 year horizon.

Chart 6.2: Benefit of increased beef production



6.1.3 Sensitivity analysis

Key variables, namely the change in carrying capacity and the price, were varied in order to observe their impacts on the estimated benefit. It was found that the estimated benefits ranged from a low of N$3.2 billion, when carrying capacity only increased by 50%, and a high of N$12.7 billion, when carrying capacity tripled. Changes in prices had a lesser impact, with estimated benefits ranging from N$5.1 billion, when the price was 20% lower, to N$7.6 billion, when the price was 20% higher.

Table 6.3: Sensitivity analysis for livestock production

Scenario	Benefit (N$m)[1]
Base case	6,371.7
Carrying capacity	
*1.5	3,185.8
*3	12,743.3
Price	
-20%	5,097.3
+20%	7,646.0

1: 2015 prices, discounted by 6% p.a.

6.1.4 Limitations and risks

There are a number of limitations and risks to this valuation.

Firstly, the relationship between carrying capacity and bush density was estimated using a rule of thumb, rather than robust data. Secondly, the forecasts of cattle numbers do not allow for influences such as weather patterns (e.g. drought), social trends, and competing industries. Thirdly, increasing stocking rates by the estimated amount may result in overgrazing if good rangeland management is not practiced, encouraging bush encroachment and perpetuating the cycle.

The price is held constant in real terms, which is unrealistic. There will be price fluctuations, which may put upward or downward pressure on stock and offtake rates.

6.2 Groundwater

In order to estimate the cost/benefit of the change in groundwater flows due to de-bushing (compared with no de-bushing), a two-step process was undertaken. The first step was to estimate the change in volume of groundwater flows (Section 6.2.1) while the second step was to estimate the monetary value of this change in volume (Section 6.2.2).

6.2.1 Estimating additional groundwater from rainfall due to de-bushing

By overlaying a map of average rainfall distribution with the map of the location and density of bush encroachment[7] (see Figure 4.5), the average rainfall per annum was visually estimated for each of the ten bush-encroached areas (Table 6.4).

The Ministry of Agriculture, Water, and Forestry (MAWF) currently assumes an average groundwater recharge rate across the entire country of 1% of Namibia's rainfall (Christelis and Struckmeier 2011). This would mean that there are currently groundwater inflows of more than 1 billion m^3 per annum in Namibia's identified bush-encroached areas. Just over 600 million m^3 per annum is estimated to be recharged over the 60% of land that we assume could be de-bushed.

Data on responses by groundwater recharge rates to de-bushing are limited. Christian et. al. (2010) cite a highly localised study of the Platveld Aquifer, where the recharge rate was estimated to improve to 8% in a de-bushed area. However, it should be noted that this estimate was based on a single rainfall event and is therefore not very robust. A more realistic estimate for the Platveld area was thought to be 4%. The authors also cite estimates of recharge rates of 6% observed in the Otavi Mountain Lands in the 1970s (before significant bush encroachment), which compares with a recharge rate of 1% in the late 1990s (under significant bush encroachment conditions). The current GIZ assignment on interpreting data from seven years of rainfall and monitoring the groundwater cycle will shed more light on this critical relationship.

We took a conservative estimate of a rise in the recharge rate to 2% to be used in the central case. If 5% of the 15.8 million targeted hectares was de-bushed per annum, and assuming that groundwater recharge rates improved linearly, it was estimated that de-bushing could result in additional groundwater recharge of just over 600million m^3 per annum after 21 years (see Table 6.4).

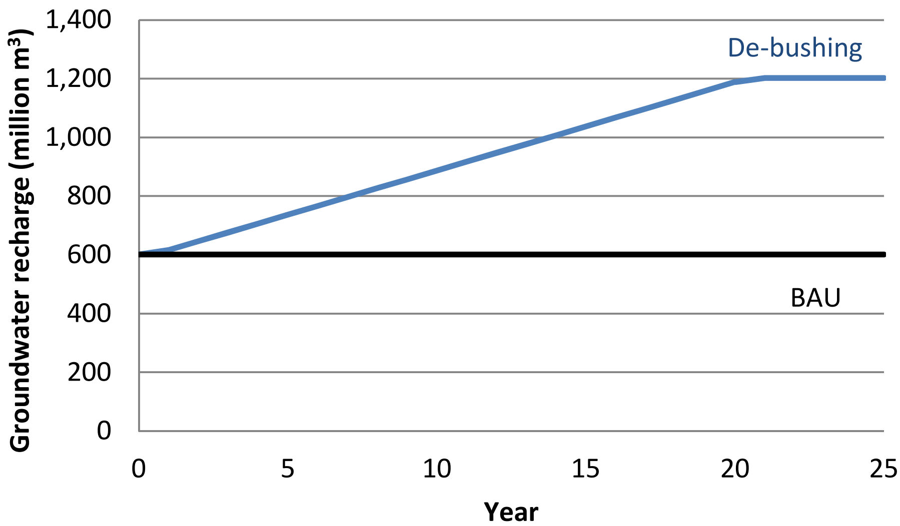
[7] In future, there is potential to link the bush-encroached zones with geological maps (which can be related to water permeability). This may result in a more accurate model for groundwater recharge.

Table 6.4: Estimate of groundwater recharge impacts from de-bushing

No. of area (map)	Total farmland (million m^2)	De-bushed farmland (60% of total) (million m^2)	Rainfall (m p.a.)	Total rainfall on de-bushed farmland (million m^3 p.a.)	Groundwater inflow at 1% recharge (million m^3 p.a.)	Groundwater inflow at 2% recharge (million m^3 p.a.)	Potential increase in groundwater inflow (million m^3 p.a.)
1	44 370	26 622	0.325	8 652	87	173	87
2	23 670	14 202	0.225	3 195	32	64	32
3	35 550	21 330	0.325	6 932	69	139	69
4	15 720	9 432	0.425	4 009	40	80	40
5	20 800	12 480	0.425	5 304	53	106	53
6	29 020	17 412	0.375	6 530	65	131	65
7	37 330	22 398	0.500	11 199	112	224	112
8	34 030	20 418	0.425	8 678	87	174	87
9	22 100	13 260	0.425	5 636	56	113	56
10	-	-	0.150	-	-	-	-
Total	262 590	157 554		60 134	**601**	**1 203**	**601**

Source: Honsbein, Peacocke, & Joubert 2009, EIS

Chart 6.3: Groundwater recharge – de-bushing versus BAU



6.2.2 Valuing the increase in groundwater volume

To value this increase in groundwater recharge, we used two different methods: the avoided cost approach (Section 6.2.2.2) and the market price approach, using bulk water tariff rates (Section 6.2.2.3).

For valuation purposes, we had to first subtract the volume of additional groundwater that would be used for the increased number of cattle due to de-bushing, as the value of this is implicit in the value of the additional beef production (see Section 6.1).

6.2.2.1 Groundwater used for livestock

To estimate the groundwater that would need to be allocated to the additional cattle, an estimate of the groundwater used per head of cattle was applied to the estimated numbers of additional cattle.

Christian et. al. (2010) cite the IWRM Plan Joint Venture Namibia (2010) which estimates that 61.3 million m^3 of groundwater was used for the livestock sector in 2009. It was assumed that 70% of this was used for cattle (42.9 million m^3) and the remaining 30% was used for other livestock. The livestock census for 2009 does not offer accurate data on total cattle numbers in Namibia, so the 2010 figure was used to approximate a volume of 18.0m^3 of groundwater consumed per head of cattle per annum.

This figure was then multiplied by the additional head of cattle per annum (due to de-bushing) to derive the total volume of groundwater that would be used for the additional cattle per annum. This was subsequently subtracted from the annual estimates of additional groundwater recharge. Over the 25-year horizon, this amounted to approximately 214 million m^3.

6.2.2.2 Valuation: avoided cost

Data from NamWater revealed that a project in Kalkfeld to increase capacity by 300m^3 per day would incur capital costs of around N$64.6 million (in 2015 prices) over its 30 year lifetime (see Table 6.5). This includes reinstallments of power supply and machinery and equipment in Year 10 and Year 20, as they are only expected to have a ten year lifespan[8].

When adjusted to the 25-year horizon used in this analysis, and with the assumption of economies of scale of 10% (due to the extrapolation across the bush-encroached area), this represents an implicit cost of around N$14.7 million per million m^3 of water.

Table 6.5: Kalkfeld water supply project – capital costs

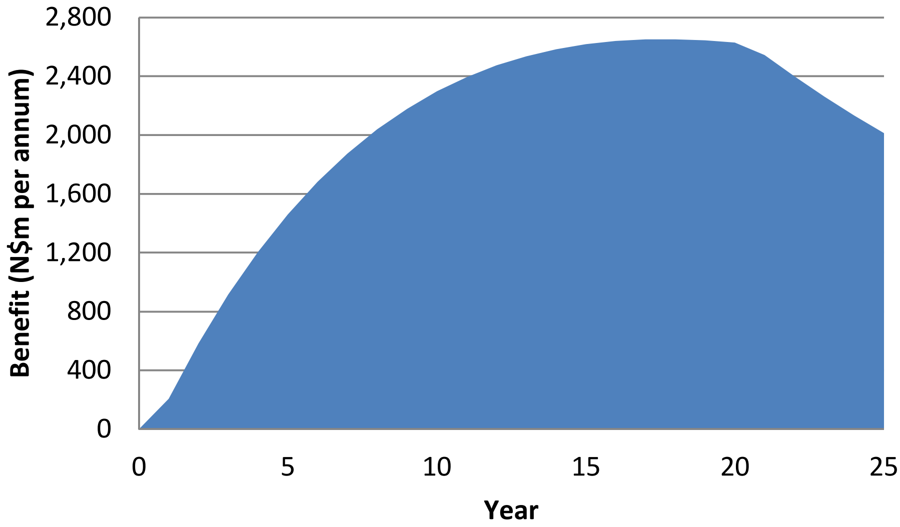
Activity	Cost (N$)[1]
Civil engineering	
Pipelines procurement & construction	33,800,000
Servitude and site clearance	4,800,000
Machinery and equipment engineering - initial	
Power supply	3,300,000
Machinery and equipment installations	5,120,000
Machinery and equipment engineering - after 10 years	
Power supply	3,300,000
Machinery and equipment installations	5,120,000
Machinery and equipment engineering - after 20 years	
Power supply	3,300,000
Machinery and equipment installations	5,120,000
Drilling and test pumping of boreholes	731,493
TOTAL	64,591,493

1: 2015 prices Source: NamWater 2015

[8] According to NamWater

The implicit cost of water was then applied to the additional recharge volumes per annum to arrive at the estimated value of the additional flow of groundwater to get an estimate of **N$51.6 billion** for the discounted benefit over the 25 year horizon.

Chart 6.4: Benefit of increased groundwater recharge



6.2.2.3 Valuation: bulk water tariff rates

As an alternative, bulk water tariffs were also used to value the additional groundwater. Tariffs don't tend to be a good reflection of economic value. Instead of being determined by the market, they are set by the government in response to applications by water companies, in this case, NamWater. However, we offer this as an alternative to and comparison with the avoided cost approach.

Table 6.6: Bulk water tariffs

Region	Tariff in 2015 (N$m/million m^3)
North	10.55
Central	13.85
South	9.35

Source: Government Gazette

The tariffs specific to the region for each bush-encroached zone were applied to the amount of additional groundwater that would be realised in each zone. The discounted benefit was estimated at **N$43.9 billion** over the 25 year horizon. As this figure is within 15% of the avoided cost figure, it underlines the robustness of our estimate.

6.2.3 Sensitivity analysis

Key variables, namely rainfall and the change in recharge rate, were varied in order to observe their impacts on the estimated benefit. It was found that the estimated benefits ranged from a low of N$25.2 billion, when the groundwater recharge rate only increased to 1.5%, and a high of N$104.4 billion, when the recharge rate increased to 3%. Changes in rainfall had a lesser impact, with estimated benefits ranging from N$41.0 billion, when average rainfall was 20% lower, to N$62.2 billion, when average rainfall was 20% higher.

Table 6.7: Sensitivity analysis for groundwater recharge

Scenario	Benefit (N$m)[1]
Base case	51,609.5
Rainfall	
-20%	41,043.2
+20%	62,175.9
Recharge rate	
1.5%	25,193.7
3.0%	104,441.3

1: 2015 prices, discounted by 6% p.a.

6.2.4 Limitations and risks

There are a number of limitations and risks to this valuation.

Firstly, the impact of de-bushing on groundwater recharge rates needs to be further researched, as the current data is very constrained in terms of location and timing. Our estimate of an increase in recharge from 1% to 2% of rainfall is conservative, but there is little data to support it. Furthermore, recharge rates would be highly variable in different locations, depending on morphology and geology.

Secondly, the cost to increase capacity has been drawn from just one project (Kalkfeld), as cost data for projects in other regions were unavailable. The implicit cost was then extrapolated across all bush-encroached zones, which does not take into account differences in abstraction regimes and water values across different locations.

A key risk here is that if de-bushing is not carried out with good environmental management practices, it could increase soil erosion, which has the potential to increase vulnerability of groundwater resources.

6.3 Utilisation of biomass

There are several options for the utilisation of biomass from de-bushing. Some are already established in Namibia, such as firewood, charcoal production, and crafts. Others are still being established or are yet to enter the market, such as electricity generation, construction materials, and animal feed.

In this study, we have estimated the costs/benefits from firewood, charcoal, and electricity production for inclusion in the cost-benefit analysis. We discuss additional options in Section 6.3.5.

Based on Zimmerman and Joubert (2002) and Honsbein et. al. (2009), we have estimated the amount of biomass that would be available for utilisation each year over the project horizon. Please see Section 6.5 for more detail on calculations. A waste factor of 10% is assumed between harvest and use.

The utilisation across the options is aggregated and, under the key assumptions, Namibia will not have the capacity to utilise the entire biomass available until after the initial round of de-bushing has been completed (Year 21). However between Year 21 and Year 25 inclusive, we estimate that, depending on re-growth parameters, demand may exceed supply in each of those years. Therefore, it would be beneficial if biomass could be stored in early years for use in later years. This would also ensure continuity of supply. The following scenarios and estimates assume that there will be capacity to store biomass for future use, rather than having to use the annual harvest in the same year, however the cost of storage is not included here.

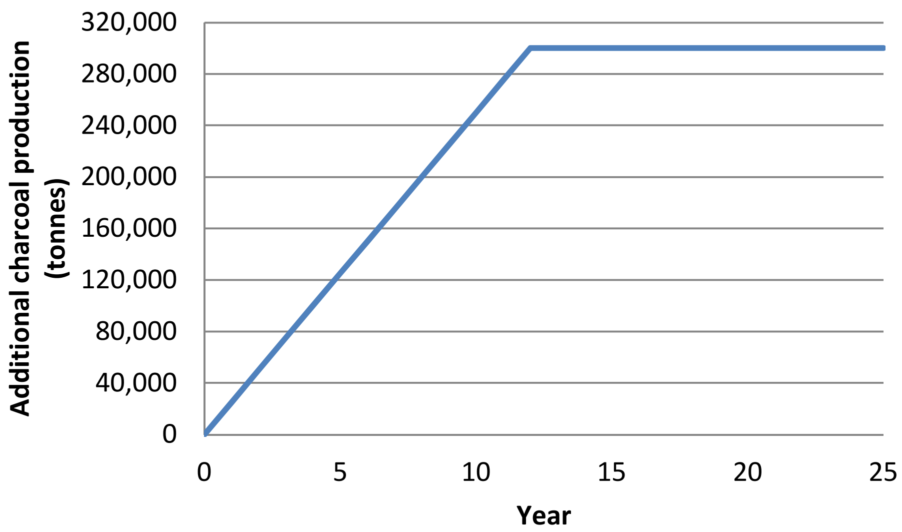
If a sustainable bush-harvesting strategy is pursued (i.e. allowing bushes to grow back in order to re-harvest rather than aiming for permanently lower bush densities), this would increase the long-run supply of biomass for utilisation. However, this would come at the detriment of livestock carrying capacities and groundwater recharge, and likely other benefits, such as tourism and biodiversity.

6.3.1 Charcoal production

Namibia currently produces an estimated 100,000 tonnes of charcoal per annum. We assume that this production would have been maintained without the specific programme of de-bushing in the bush-encroached zones. Therefore, the value of 100,000 tonnes of production each year cannot be considered a benefit of de-bushing. However, if harvesting for charcoal production shifts from tree sources, overexploitation of bushes, or de-bushing in vulnerable areas, this would represent an avoided cost (i.e. benefit).

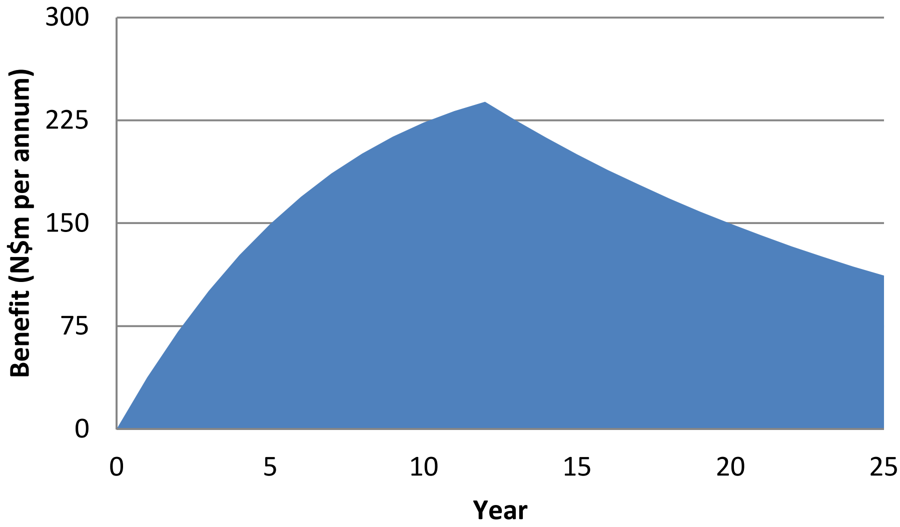
We instead assume that production of charcoal will increase above the 100,000 tonnes, supported by the increased supply of woody biomass and overseas demand. From a base of zero additional tonnes in Year 0, we assume that charcoal production will increase by 25,000 tonnes per annum until it reaches 300,000 additional tonnes (an increase of 300%) by the end of the twelfth year, and then plateau.

Chart 6.5: Additional charcoal production due to de-bushing



These volumes are multiplied by the current real average wholesale price of charcoal of N$1,600 per tonne to estimate the benefit of the increase in charcoal production due to de-bushing. The discounted benefit was estimated at **N$4.1 billion** over the 25 year horizon.

Chart 6.6: Benefit of increased charcoal production



6.3.1.1 Sensitivity analysis

The price of charcoal was varied in order to observe the impact on the estimated benefit. It was found that the estimated benefits ranged from a low of N$3.2 billion, when the price was 20% lower, and a high of N$4.9 billion, when the price was 20% higher.

Table 6.8: Sensitivity analysis for charcoal production

Scenario	Benefit (N$m)[1]
Base case	4,060.6
Price	
-20%	3,248.5
+20%	4,872.7

1: 2015 prices, discounted by 6% p.a.

6.3.1.2 Limitations and risks

There are upside and downside risks to demand for charcoal. Namibia currently exports a significant proportion of its charcoal to Europe. Increases in demand from Europe, the expansion of Namibia's market share, or entry into new markets, such as the Near, Middle, and Far East, may all put upward pressure on demand for Namibian charcoal, whereas competition from other sources may reduce it.

In terms of supply, charcoal producers may have to compete with other industries to secure supply. Fluctuations in supply and demand will affect prices, which we have held constant in real terms.

6.3.2 Electricity generation

Our analysis of the potential benefits of electricity generation is based on scenarios outlined in the *Prefeasibility Study for Biomass Power Plant, Namibia: Power Plant Technical Assessment*. The development of ten 5MW plants (type 1), three 20MW plants using grate combustion with steam turbine, with the additional energy input of heated air (type 2a), and three 20MW plants using grate combustion with steam turbine, with no additional energy input (type 2c) was envisaged.

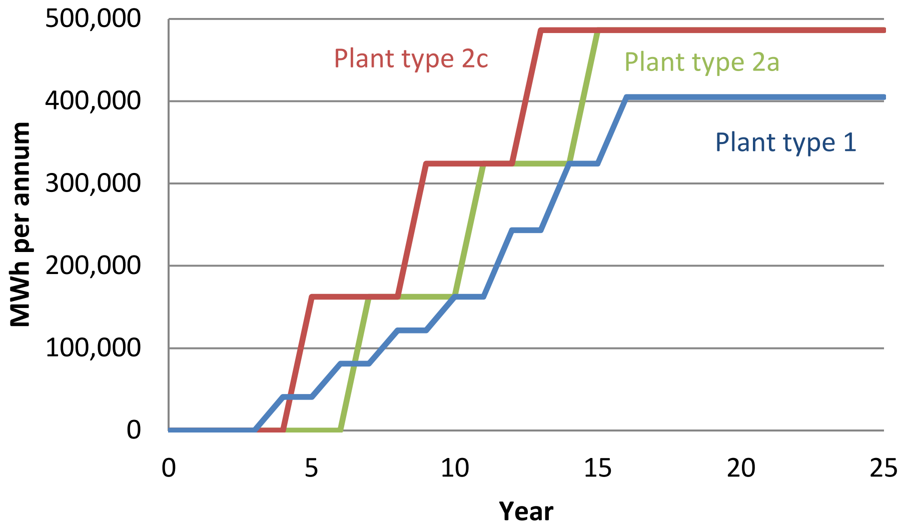
Table 6.9: Output and biomass consumption by type of power plant

Type of plant	Biomass consumption (tonnes p.a.)	Output (MW p.a.)
5MW grate (type 1)	45,247	40,500
20MW grate (type 2a)	147,226	162,000
20MW grate (type 2c)	154,386	162,000

Source: Theeboom 2012

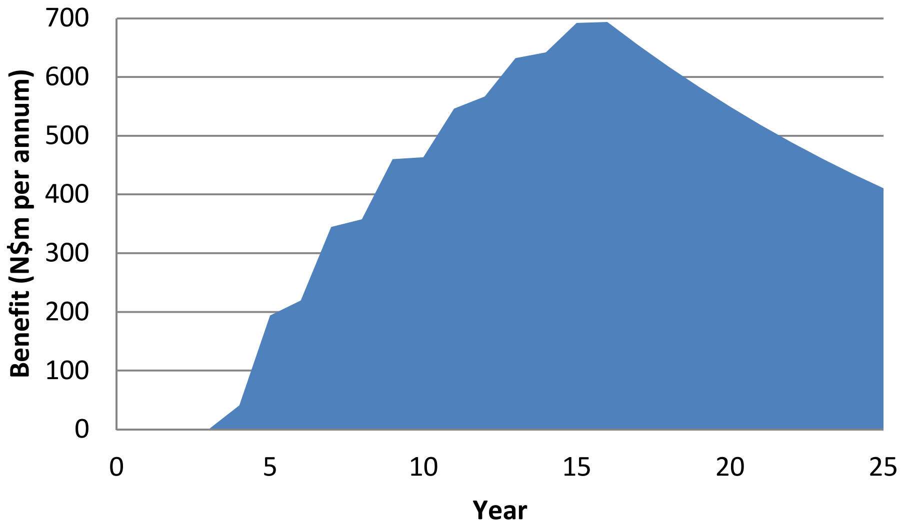
It was assumed that no plants would be operational in the first three years. A 5MW plant would enter production in Year 4, with additional 5MW plants entering production in Years 6, 8, and 10, and two entering production annually in Years 12, 14, and 16, to total 50MW. In Year 5, a 20MW plant (type 2a) would enter production, with additional plants entering production in Year 9 and 13, to total 60MW. In Year 7, a 20MW plant (type 2c) would enter production, with additional plants entering production in Year 11 and 15, to total 60MW. On this schedule, capacity would reach 170MW by Year 16. The study assumes a total of 8100 operational hours per annum per plant.

Chart 6.7: Electricity generation from de-bushed biomass



The average price of electricity was taken as the current average tariff of N$1.28/kWh and multiplied by the total output (in kWh) to estimate the total revenue from biomass-driven electricity production, according to the above assumptions. The discounted benefit was estimated at **N$10.6 billion** over the 25 year horizon.

Chart 6.8: Benefit of increased electricity generation



6.3.2.1 Sensitivity analysis

It was thought that the most realistic risks to these estimates would be on the downside. Firstly, the forecast for an increase in capacity to 170MW would require political support and significant investment by both the public and private sectors. A slower escalation, with peak capacity of only 110MW (by Year 19), would result in an estimated benefit of $7.3 billion.

NamPower estimates that the breakeven price for biomass-fuelled electricity would be N$2.00 to N$2.20/kWh[9][10]. This would be significantly higher than the current electricity tariff of around N$1.28/kWh. It is therefore reasonable to expect that the government would have to subsidise electricity to the tune of N$0.72/kWh, which represents a cost to society (see Section 6.3.2.2 for more information). Consequently, the net economic value of the additional electricity supply could be much lower. If the net economic value was 20% lower, the benefit is estimated at N$8.5 billion over the 25 year horizon, but it could be much lower than this.

Table 6.10: Sensitivity analysis for electricity production

Scenario	Benefit (N$m)[1]
Base case	10,572.1
Capacity of 110MW	7,330.8
Net economic value (N$/kWh)	
-20%	8,457.7

1: 2015 prices, discounted by 6% p.a.

[9] NamPower (pers. comm.)

[10] Although this is higher than the current tariff of N$1.28, it is lower than the Kudu power plant's estimated breakeven price of N$2.55. This implies lower production costs for a biomass power plant compared with the Kudu plant proposal.

6.3.2.2 Limitations and risks

There is a significant risk that the envisaged capacity will not be reached either within the timeframe or at all. As mentioned above, it would require political support and significant investment by the private sector. The recent shift towards favouring renewables over developing the Kudu gas project is a good sign, but is no guarantee that there will be enough support and investment to reach the envisaged capacity of 170MW[11]. Changes in the plant technology or different types of plants may also alter the fuel requirements (woodchips).

The current electricity tariff of N$1.28/kWh is not a market price, so may not reflect the true economic value of the additional electricity. Furthermore, NamPower estimates that the breakeven price of electricity from a biomass-fuelled power plant would be around N$2.00 to N$2.20/kWh[12]. The difference would need to be subsidised by the government – around N$0.72/kWh – which represents a cost to society. However, there may also be avoided costs in comparison with other electricity sources, which could have even higher production costs, and therefore breakeven rates.

6.3.3 Firewood

Current demand for firewood in Namibia is estimated at 550,000 tonnes per annum (Development Consultants for Southern Africa 2015). We assume that this production would have been maintained without the specific programme of de-bushing in the bush-encroached zones, but we also assume that the increased supply of firewood from encroacher bush would offset some of the 550,000 tonnes sourced from non-encroacher bush. As this offset may shift collection of wood from tree sources, overexploitation of bushes, or de-bushing in vulnerable areas, this would represent an avoided cost (i.e. benefit). We have valued this avoided cost at the difference between fair trade and non-fair trade prices for charcoal (also derived from woody plants) which is equal to around 10%.

From a base of zero additional tonnes in Year 0, we assume that 100,000 tonnes of non-encroacher firewood production would be offset in Year 1, with further offsets of 5,000 tonne increments each year, up until it reaches an offset of 175,000 tonnes by Year 16, then plateaus. Additional firewood production starts at 5,000 tonnes in Year 2 and increases in 5,000 tonne increments until it reaches 75,000 additional tonnes by Year 16, then plateaus. Unlike charcoal, which can be exported, demand for firewood is unlikely to increase by as much, particularly with Namibia's rural electrification plans. However, urbanisation and movement into informal settlements may increase demand for firewood somewhat.

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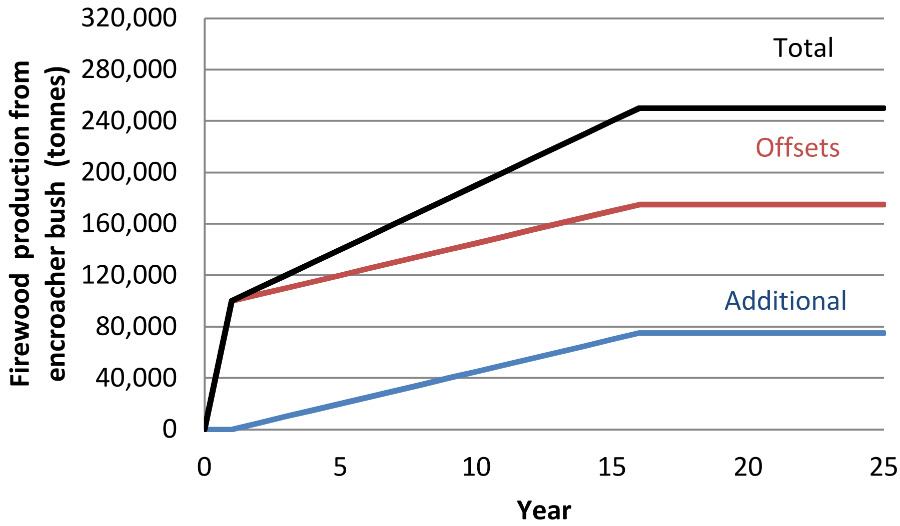
[11] http://allafrica.com/stories/201511051619.html

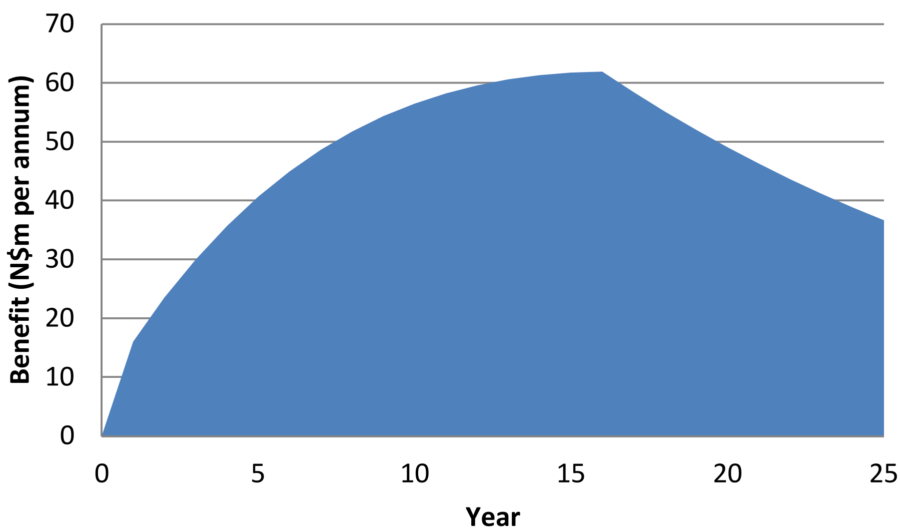
[12] Around 33-40% of the production costs that result in this higher breakeven price include the costs of woodchips.

Chart 6.9: Offsetting and additional firewood production due to de-bushing



The additional volumes were multiplied by the real retail price of firewood of N$1,700 per tonne. The offset volumes were multiplied by 10% (the rough difference between fair trade and standard prices) of the retail price of firewood. Together, this resulted in an estimate of the value of the increase in firewood production due to de-bushing. The discounted benefit was estimated at **N$1.2 billion** over the 25 year horizon.

Chart 6.10: Benefit of increased firewood production



6.3.3.1 Sensitivity analysis

The price of firewood was varied in order to observe the impact on the estimated benefit. It was found that the estimated benefits ranged from a low of N$949 million, when the price was 20% lower, and a high of N$1.4 billion, when the price was 20% higher.

Table 6.11: Sensitivity analysis for firewood

Scenario	Benefit (N$m)[1]
Base case	1,186.2
Price	
-20%	948.9
+20%	1,423.4

1: 2015 prices, discounted by 6% p.a.

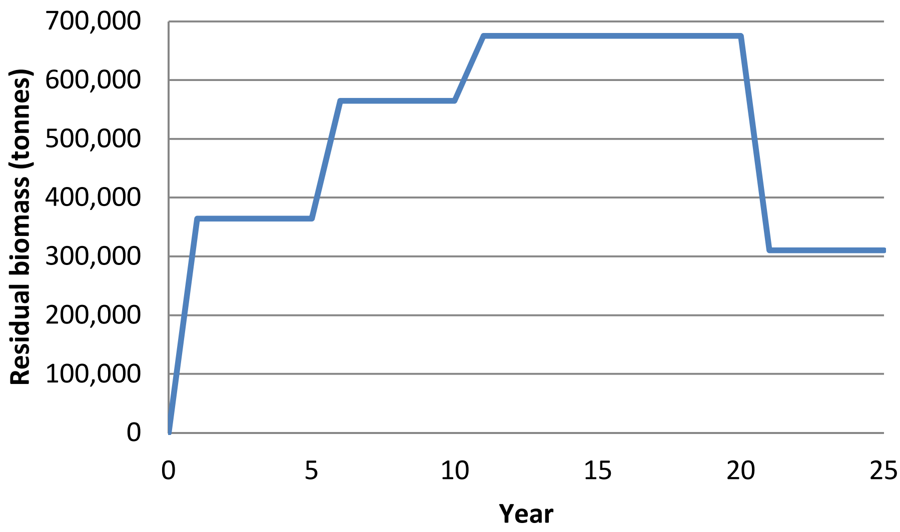
6.3.3.2 Limitations and risks

The forecasts for escalation in demand for firewood (and hence production quantity) and the amount that would be offset are not backed up by robust data.

6.3.4 Residual biomass as mulch

Many studies recommend that some of the de-bushed biomass be left on the ground to return nutrients to the soil and provide some protection for new grasses coming through. Leaves and twigs are not considered useful for charcoal, electricity, and firewood production, so we suggest that these are left on the land. Smit et. al. (2015) provide estimates of leaf and twig mass to woody mass in different encroacher bushes. We take an estimate of 15% from here.

Chart 6.11: Residual biomass from de-bushing

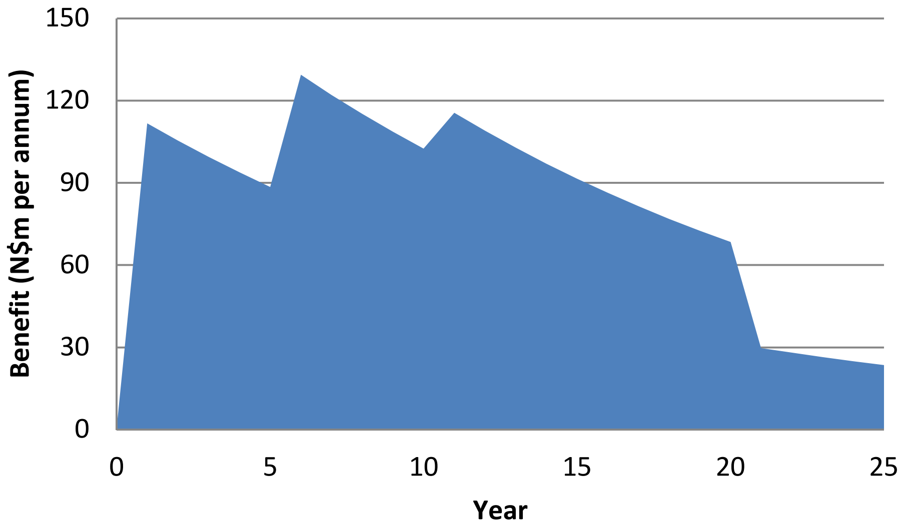


To value the benefits of this residual biomass that is left on the ground, we take a price for mulch. For a cubic metre of mulch in South Africa, the price is R130 (=N$130)[13]. A weight-to-volume estimate of 400kg/m^3 was used to arrive at a price of N$325/tonne of residual biomass.

The volume was then multiplied by this price to estimate the value of the residual biomass left on the ground after to de-bushing. The discounted benefit was estimated at **N$2.1 billion** over the 25-year horizon.

[13] http://www.reliance.co.za/productpricelist.html

Chart 6.12: Benefit of residual biomass



6.3.4.1 Sensitivity analysis

The value of the residual biomass was varied in order to observe the impact on the estimated benefit. It was found that the estimated benefits ranged from a low of N$1.7 billion, when the price was 20% lower, and a high of N$2.5 billion, when the price was 20% higher.

If the proportion of the weight of leaves and twigs to woody biomass was only 10%, or if the equivalent of only 10% was left on the ground, rather than 15%, the benefit was estimated at N$1.4 billion.

Table 6.12: Sensitivity analysis for residual biomass

Scenario	Benefit (N$m)[1]
Base case	2,110.0
Price	
-20%	1,688.0
+20%	2,532.0
Volume	
10% of harvest	1,406.7

1: 2015 prices, discounted by 6% p.a.

6.3.4.2 Limitations and risks

There is a risk that to make it easier, all the biomass is extracted, rather than leaving some behind.

6.3.5 Other opportunities

The increased supply of woody biomass could also have other uses.

Wooden crafts are traditionally made in Namibia, so de-bushing could support increases in production. Construction materials can also be produced from de-bushed biomass, including poles, wood cement, medium-density fibre boards, wood-plastic composites, and wooden frames. Poles are currently produced at an estimated 334,000m² per annum, but are also imported. The other materials appear to be either niche industries or currently not produced in Namibia at the moment. Increased supply of biomass could support growth in these industries.

Biomass from encroacher bush can also be used as an input into animal feed. For example, Tambuti, a mixed-use farm in the Otavi area, already produces its own animal feed from de-bushed biomass on its property, and is looking to begin selling to other farmers in 2016. According to Larry Bussey from Tambuti, between 50% and 85% of a tonne of animal feed can come from woody biomass, with a market price of between N$200 to N$325 per 40kg bag.

Namibia Breweries Limited has piloted the use of a woodchip boiler for the generation of process heat. This technology is already well-established in Europe and elsewhere and could be expanded into other industries, such as meat and fish production. There are many other uses of woody biomass that are widespread outside of Namibia, such as the production of wood-plastic composites. These represent further, and potentially profitable, opportunities for Namibia to utilise encroacher.

Bush banks, where biomass from de-bushing is stored and can be sold from, are enterprises that could potentially increase ease of access to wood, supporting growth in the above industries. This is also a way of profiting from the excess biomass in the early years of de-bushing, when Namibia will not be able to utilise its entire capacity.

6.4 Carbon sequestration

6.4.1 Existing evidence

Studies assessing the impact on carbon sequestration of changes in land cover relating to bush encroachment have largely focused on changes from grassland or savannah to bush cover. However evidence from these studies is mixed. Studies presented by Wessman et al. (2004) illustrated that the response of the storage of soil organic carbon (SOC) ranged from decreases to significant increases when moving from grassland to bush cover, while Hudak et al. (2003) found evidence of non-monotonic responses based on the level of bush cover.

A recent paper by Blaser et al. (2014) assessed results from 15 studies across 21 different locations mostly in the US, and found a range of changes in carbon sequestration in soil following woody encroachment of between -80gC/m^2 per annum to 239gC/m^2 per annum, with an average of 21gC/m^2 per annum. In their own analysis of soil samples from Zambia, they found a response of between 12 and 16gC/m^2 per annum. The evidence seems to indicate that there is a broadly positive impact from bush encroachment on soil carbon sequestration, but that it is likely to be location and context-specific.

An attempt is made to value the impact of the change in carbon sequestration as a result of de-bushing in Namibia. The values presented should be taken as only broadly indicative given the assumptions that need to be made to elicit a value, and the location- and context-specific nature of the rate of carbon sequestration.

6.4.2 Economic valuation of carbon sequestration from de-bushing

Several different values have been attached to carbon. The US Environmental Protection Agency (EPA) uses the Social Cost of Carbon (SCC) as an estimate of the economic damages associated with a small increase in carbon dioxide (CO_2) emissions (US EPA, 2015). The central estimate of the SCC of a tonne of CO_2 emitted in 2015 is approximately US$40 in 2014 prices (US$40.1 in 2015 prices), rising to US$77 by 2050. The *State of Voluntary Carbon Markets*[14] indicates that the average prices of voluntary carbon offsets traded in markets in 2014 was US$3.8/t$CO_2$e. The average carbon market price under the EU Emissions Trading Scheme (ETS) in 2015 was €7.8/ tCO_2e.

We have chosen to use a value of N$60/t$CO_2$e which is currently being used for the National Integrated Resource Plan review. This is the only value that we know of that is used in the Namibian context. Although it is not based on an actual market, this value is very close to the average price of voluntary carbon offsets traded in markets (US$3.8/t$CO_2$e), which gives it a measure of robustness.

In order to estimate a value for carbon sequestration from de-bushing, the impacts have to be expressed in tonnes of CO_2 per year.

Table 6.13: Estimate of carbon sequestration impacts from de-bushing

	Carbon sequestration	Source
(1) Change in carbon sequestered from grassland to bush (gC/m^2/yr)	21	Blaser et al. (2014)
(2) Invert to estimate impact of debushing	-1	Assumption
(3) Convert to CO_2 from C	3.67 units CO_2 = 1 unit of C	-
(4) Convert to tonnes from grams	1000000 grams = 1 tonnes	-
(5) Convert to ha from m^2	10000 m^2 = 1 ha	-
(6) Change in CO2 sequestered from debushing (tCO_2/ha/yr)	**-0.771**	**Calculation: (1)*(2)*(3)*(5)/(4)**

The starting point is provided by the average of the Blaser et al. (2014) range of impacts in terms of the change in grams of carbon per m^2 per year. We make two key assumptions here. Firstly, due to Namibia's relatively low levels of soil organic carbon, we assume that the capacity of the soil to sequester carbon is only reduced in the year of de-bushing, rather than annually. Secondly, we assume that the inverse of these estimates can be applied as an approximation of the benefits/costs in terms of carbon sequestration when de-bushing to remove woody encroachment. The impacts are then transformed into tonnes of CO_2 per hectare sequestered. This process is presented in Table 6.13; the resulting estimate is a reduction in tonnes of CO_2 sequestered per hectare per year of 0.77.

To generate an estimate of the real economic costs or benefits of de-bushing in terms of carbon sequestration, the impacts estimated in Table 6.13 are multiplied by the Namibian offset value of N$60 for a given year and the total hectares of land de-bushed by the end of that year. Table 6.14 presents the calculation for the real costs or benefits of de-bushing in 2016[15], assuming that 5% (787,770 ha) of bush encroached land is de-bushed to one third of its current density. This represents a discounted cost of N$22.91 million in 2015 prices.

[14] http://forest-trends.org/releases/uploads/SOVCM2015_FullReport.pdf
[15] This report assumes that de-bushing starts in 2016.

Table 6.14: Estimate of costs or benefits from carbon sequestration as a result of de-bushing in 2016

	Carbon sequestration	Source
(1) Change in CO_2 sequestered from debushing (tCO_2/ha/yr)	-0.771	Table 6.13
(2) Theoretical carbon price in Namibia (N$)	60.00	NIRP (2015)
(3) Total de-bushed land by 2016 (ha)	787,770	Author's own
(4) Decrease in bush density	67%	Author's own
(5) Apply a real discount rate of 6% (Discount Factor)	0.9434	
(6) Real economic costs / benefits from carbon sequestration in 2016 in 2015 prices (N$m)	**-22.91**	**Calculation: (1)*(2)*(3)*(4)*(5)*(6)**

Over the 25 year time horizon used for this study, it is possible to calculate the net present value (NPV) of carbon sequestration. This assumes that the same area of land is de-bushed each year, the real Namibian carbon offset value remains constant, and a real discount rate of 6% is applied consistently across the time period. Based on the estimate of a change in -0.771 tCO_2/ha per annum, the NPV represents a cost of N$278.6 million in 2015 prices.

There are a number of assumptions in the above calculations which are particularly strong. The simple inversion of sequestration estimates undertaken in (2) of Table 6.13 is necessary given the lack of evidence going in the other direction, and may well overstate the true change in carbon sequestration. Furthermore, the estimates of changes in carbon sequestration taken from Blaser et al. do not make clear the underlying level of bush density, and whether it is representative of the situation in Namibia. The assumption undertaken in (4) of Table 6.14, that because only a proportion of the bush is cleared the impacts can be scaled by the proportion that is cleared, is also very strong; there may be non-linear or threshold effects at work.

Only a point estimate is presented above, although as discussed in Section 6.4.1, the existing evidence presents a range of estimates of the impact on carbon sequestration from moving bush encroachment on grassland. These estimates would represent a range of values for the change in carbon sequestered due to de-bushing 787,770 hectares in 2016 from a cost of N$260.7 million to a benefit of N$87.3 million, corresponding to NPVs of -N$3.2 billion to N$1.1 billion over the 25 year horizon. This range of estimates is not presented to demonstrate a range of values that would be applicable to Namibia, but rather to illustrate the considerable uncertainty in the literature about the impacts of de-bushing on carbon sequestration.

There will be further impacts on net carbon sequestration in Namibia based on how the de-bushed material and/or land are used. Two key issues are the use of de-bushed material to produce electricity, and the exploitation of the anticipated increased carrying capacity of land to farm more cattle. These are explored in Sections 6.4.3 and 6.4.4, respectively, below.

6.4.3 Electricity generation

As discussed in Section 6.3.2, the project specifies that de-bushed material would be used to generate electricity through biomass power plants, with three types of plants, each with specific timelines for their development, envisaged. The impact on net carbon sequestration in Namibia depends on whether this electricity generation is additional to or replaces other grid sources, and whether the harvesting of bush for this purpose prevents the burning of bush-encroached areas.

Table 6.15: Cost of emissions from a single biomass power plant development of each type

	Power plant type			Source
	1	2a	2c	
(1) Size of power plant (MW)	5	20	20	WSP (2012)
(2) Hours operational		8100		WSP (2012)
(3) Electricity generated (MWh per annum)	40,500	162,000	162,000	Calculation: (1)*(2)
(4) Emissions generated (tCO_2/MWh)	0.026	0.031	0.032	WSP (2012)
(5) Total emissions (tCO_2 per annum)	1,053	5,022	5,184	Calculation: (3)*(4)
(6) Theoretical carbon price in Namibia (N$/$tCO_2$)		60.00		NIRP (2015)
(7) Total cost of emissions (N$ per annum)[1]	**63,180**	**301,320**	**311,040**	**Calculation: (5)*(6)**

1: undiscounted

Table 6.15 presents an assessment of the total direct CO_2 emissions generated by the three different types of biomass power plant development in Namibia in the first year of their operation. Emissions are calculated based on assumptions in WSP (2012), and the emissions factor includes the effects of both the supply chain and the combustion of biomass residues. As would be expected, the power plants that generate more energy also produce more emissions; they also have slightly higher emissions factors.

However this does not represent the net effect on CO_2 emissions in Namibia if it replaces other sources of electricity for grid energy and prevents the burning of bush as an approach to alleviating bush encroachment. The average emissions factor for electricity in Namibia is estimated at 0.4898 tCO_2/MWh (WSP, 2012); consequently if these emissions are displaced, the net change in CO_2 emissions is between -0.4638 and -0.4578 tCO_2/MWh. Furthermore, methane emissions from burning the equivalent area of bush encroached land required to generate 1MWh are estimated at between 0.032 to 0.040 tCO_2e[16] (IPCC, 2006).

Estimates of the net effects on CO_2e emissions in Namibia across the three power plant types are presented in Table 6.16; for each plant of type 1, more than 20,000 tCO_2e would be avoided annually if biomass energy generation displaced grid energy and prevented methane emissions from burning equivalent areas of bush encroached land, increasing to almost 80,000 tCO_2e for plant types 2a and 2c.

[16] tCO_2e denotes tonnes of carbon dioxide equivalent.

Table 6.16: Net CO_2e emissions in Namibia from a single biomass power plant development of each type

tCO_2e per annum	Power plant type		
	1	2a	2c
Direct emissions from biomass electricity generation	1,053	5,022	5,184
Net emissions if displacing grid energy	-18,784	-74,326	-74,164
Net emissions if displacing grid energy and preventing burning of bush encroached land	-20,404	-79,510	-79,510

These emissions can be valued in the same way as in Table 6.14. Table 6.17 illustrates that the annual economic costs of CO_2e emissions resulting from a single type 1 plant range from N$63,180 when only considering direct emissions from biomass electricity generation, to -N$1.2 million (where negative values denote avoided costs) when considering avoided emissions from displacing grid energy and preventing burning of bush encroached land. For plant type 2a, the range of costs is estimated at N$301,320 to -N$4.8 million. For plant type 2c, a range of N$311,040 to -N$4.8 million is estimated.

Table 6.17: Economic costs of net CO_2e emissions in Namibia from a single biomass power plant development of each type

N$[1] per annum (undiscounted)	Power plant type		
	1	2a	2c
Direct emissions from biomass electricity generation	63,180	301,320	311,040
Net emissions if displacing grid energy	-1,127,034	-4,459,536	-4,449,816
Net emissions if displacing grid energy and preventing burning of bush encroached land	-1,224,234	-4,770,576	-4,770,576

1: 2015 prices

Over the full timescale of the project, additional power plants would be added: by Year 16 there would be 10 type 1 plants for a capacity of 50MW, 3 type 2a plants would have a capacity of 60MW in the 13th year and 3 type 2c plants would reach a capacity of 60MW in the 15th year. The total net CO_2e emissions over the 25 year lifetime of the project under the three different scenarios are presented in Table 6.18. Plant type 2a would represent the largest avoided emissions if displacing grid energy and preventing the burning of bush encroached land, at a total of 4.1 million tCO_2e.

Table 6.18: Total net CO_2e emissions in Namibia from each type of biomass power plant development over the 25-year horizon

tCO_2e	Power plant type		
	1	2a	2c
Direct emissions from biomass electricity generation	155,844	256,122	233,280
Net emissions if displacing grid energy	-2,780,017	-3,790,606	-3,337,362
Net emissions if displacing grid energy and preventing burning of bush encroached land	-3,019,777	-4,054,990	-3,577,932

These net emissions can be valued as previously. Applying a 6% real discount rate, the NPV of the costs of the direct emissions from biomass electricity generation is between N$3.5 million (plant type 1) and N$6.1 million (plant type 2a). If considering the avoided costs from displaced grid energy and the prevention of the burning of bush encroached land, the benefits are estimated at between -N$68.1 million (plant type 1) and -N$96.8 million (plant type 2a).

Table 6.19: Total economic costs of net CO_2e emissions in Namibia from each type of biomass power plant development over the 25-year horizon

N$[1]	Power plant type		
	1	2a	2c
Direct emissions from biomass electricity generation	3,516,630	6,114,182	5,218,527
Net emissions if displacing grid energy	-62,731,275	-90,489,895	-74,657,559
Net emissions if displacing grid energy and preventing burning of bush encroached land	-68,141,475	-96,801,309	-80,039,165

1: 2015 prices

While electricity generation from biomass sources would be unlikely to immediately displace grid energy, the development of such power plants would relieve pressure on Namibia's supply and mean that more polluting sources could be avoided. However it is not clear that the project would prevent the burning of bush encroached areas. Consequently, the estimates of avoided emissions from displacing grid energy are favoured.

6.4.4 Livestock farming

A major benefit of de-bushing is increasing the carrying capacity of rangeland, which can in turn be used to produce more beef from farming cattle. However, greater numbers of cattle will increase GHG emissions; an additional kilogram live-weight of cattle is estimated to contribute an additional 11.93 $kgCO_2e$ per year[17].

Table 6.20 presents an estimate of the additional CO_2e emissions from the increased carrying capacity of rangeland in 2016. Based on estimates of increased carrying capacity from de-bushing versus a business as usual (BAU) scenario (Section 6.1), an additional 10,653 head of cattle are

[17] http://beefandlamb.ahdb.org.uk/news/livestock-and-the-environment/livestock-and-climate-change-the-facts/.

assumed to be present on Namibian rangeland. At an average live-weight of 297kg[18] per head, and with emissions of 11.93 kgCO_2e per kg live-weight, additional emissions of 37,745 tCO_2e in 2016 are estimated. As the de-bushing and BAU scenarios further diverge over the 25 year study period, this would correspond to total additional emissions of 42.3 million tCO_2e.

Table 6.20: Estimate of CO_2e emissions from additional livestock carrying capacity in 2016

	Carbon sequestration	Source
(1) Additional head of cattle	10,653	Section 6.1.1
(2) Average liveweight (kg)	297	Venter (2015)
(3) Emissions per kg liveweight (kgCO2e)	11.93	Footnote 10
(4) Convert to tonnes from kg	1,000	
(5) Additional emissions (tCO_2e)	**37,745**	**Calculation: (1)*(2)*(3)/(4)**
(6) Theoretical carbon price in Namibia (N$)	60.00	NIRP (2015)
(7) Apply a real discount rate of 6% (discount factor)	0.94	
(8) Real economic costs / benefits from additional livestock emissions in 2016 in 2015 prices (N$m)	**2.14**	**Calculation: (5)*(6)*(7)**

This can be valued using the Namibian carbon offset value as demonstrated in previous sections. The real cost of additional CO_2e emissions in 2016 is estimated at N$2.1 million (discounted), and adopting a 6% real discount rate over the 25 year study period yields an estimate of the present value of costs of N$982.0 million.

6.4.5 Summary

Table 6.21 presents estimates of the net change in CO_2e emissions as a result of de-bushing and the resulting activities over the 25 year timeline. Emissions are estimated to increase by 40.5 million tonnes CO_2e; emissions from additional head of livestock on rangeland as a result of increased carrying capacity exceed the total increase in CO_2e, but the avoided cost of emissions due to biomass-fuelled electricity production more than offsets the cost of lost SOC due to de-bushing.

Table 6.21: Estimate of total net change in CO_2e emissions from de-bushing and resulting activities

	Million tCO_2e emissions
Debushing	8.10
Electricity production	-9.91
Additional livestock	42.27
Total	**40.46**

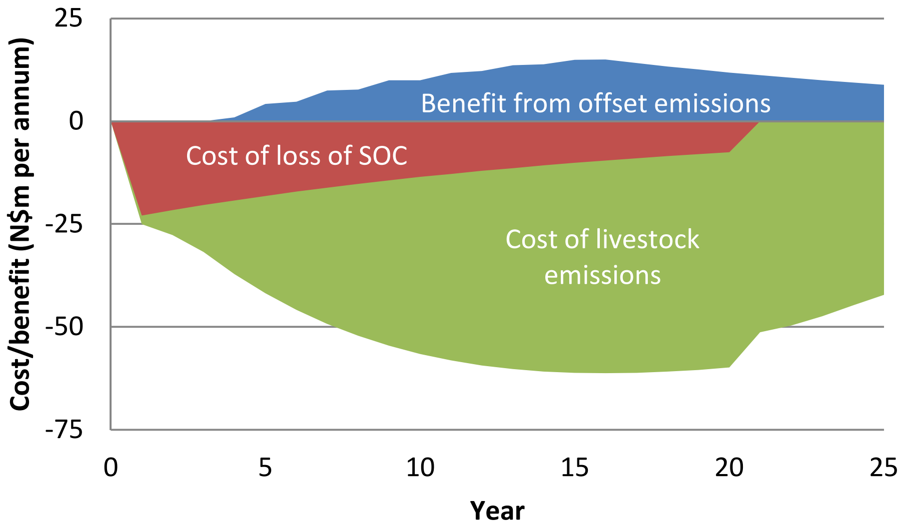
[18] Based on approx. 244 kg carcass weight: http://breedplan.une.edu.au/tips/Interpreting%20South%20African%20Simbra%20Selection%20Indexes.pdf

The estimates of total CO_2e emissions can in turn be used to estimate the NPV of de-bushing and its resulting activities in terms of its effects on CO_2e. The resulting costs from the additional farming of livestock are very large, and contribute significantly to the estimated net cost of N$1.0 billion resulting from impacts on CO_2e emissions.

Table 6.22: Estimate of present value of costs from CO_2e emissions from de-bushing and resulting activities

	N$m[1]
Debushing	278.55
Electricity production	-227.88
Additional livestock	982.01
Total	**1,032.68**

Chart 6.13: Cost/benefit of loss of SOC, additional livestock emissions, and offset emissions



6.4.5.1 Sensitivity analysis

The estimates in Table 6.22 use the Namibian carbon offset value of N$60 to generate a monetary value for CO_2 emissions, but as mentioned above, there are alternative values. The SCC puts a particularly large value on CO_2 emissions as it is based on the potential cost of damages; other market-based values are currently significantly lower. For example the UK has short-term traded values[19] of carbon of £4.66/tonne in 2016 (approximately N$89.47, compared to N$508.35 from the SCC). However, the UK rates then grow at a much faster rate, increasing to £41.51/tonne in 2025 (N$796.99), while the SCC increases to US$51/tonne (N$626.23) over the same period. Consequently emissions occurring further in the future are valued higher under the UK guidance than the US SCC.

[19] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360277/Updated_short-term_traded_carbon_values_used_for_UK_policy_appraisal__2014_.pdf

There is no particular reason, however, to apply the UK guidance to Namibia; the traded values apply to those activities covered under the EU Emissions Trading Scheme (EU ETS), of which Namibia is obviously not a part. Indeed, Namibia does not appear to have clear guidance on how to value carbon emissions for policy appraisal at a domestic level.

As discussed above, in the absence of clear guidance at a domestic level, we have chosen to use a value of N$60/t$CO_2$e, which is currently being used for the National Integrated Resource Plan review. However, if the full economic and environmental costs are taken into account, then the adoption of the US SCC likely represents best practice.

Table 6.23 illustrates how the costs (and avoided costs) vary depending on the carbon value used. The central case, using the Namibian offset value, would result in a net cost of N$1.0 billion over the 25-year horizon. Using the SCC, the net cost would be almost twelve times that, at N$12.3 billion.

Table 6.23: Sensitivity analysis for carbon

Cost (N$m)[1]	Loss of SOC	Offsets	Livestock emissions	Total
Namibian offset value	278.6	-227.9	982.0	1,032.7
SCC	2,843.3	-1,934.6	11,377.5	12,286.2

1: 2015 prices, discounted by 6% p.a.

6.5 Tourism

As discussed in Section 5.3, dense bush can have negative impacts on both consumptive (e.g. hunting) and non-consumptive (e.g. wildlife viewing) tourism. However, to our knowledge, no research has been undertaken on the quantitative impacts of de-bushing on tourism and the resultant economic benefits.

In order to provide a very rough estimate of the scale of potential benefits from de-bushing in relation to tourism, we assess the potential benefits from hunting operations. Venter (2015) estimates gross farming income from wildlife-based uses for three mixed use (cattle and hunting) farms, as well as one game-only farm. The gross income from wildlife-based uses for mixed use farms ranges from approximately N$74/ha to N$170/ha, whilst the game-only farm generates around N$478/ha. This data is presented in Table 6.24.

Table 6.24: Estimate of gross farming income from wildlife-based uses on different farms

	Mixed 1	Mixed 2	Mixed 3	Game-only
Size (hectares)	7,500	7,500	10,000	7,500
Gross farming income from wildlife-based uses (N$)	1,276,800	554,400	1,446,960	3,582,000
Gross income per ha (N$/ha)	170	74	145	478

Source: Venter 2015

De-bushing could mean that such operations become increasingly viable over a wider area of land as wildlife carrying capacities increase and the hunting experience is improved. To estimate the potential benefits from de-bushing in this regard, we apply an average of the gross income per hectare from wildlife-based uses on the three mixed-use farms to a proportion of the land that is de-bushed. Table 6.25 presents this calculation under the assumption that 10% of de-bushed land is mixed use for hunting and cattle farming, and adopting a one year delay between de-bushing and the hunting operation commencing.

Table 6.25: Estimate of potential benefits from recreational hunting on de-bushed land in 2017

	Estimate/ assumption	Source
(1) Hectares of land de-bushed in 2016	787,770	Section 3.3.1
(2) Proportion de-bushed land devoted to mixed use	10%	Author's own
(3) Average gross income from wildlife-based uses per hectare (N$)	129.62	Table 6.24
(4) Discount factor for 2017	0.89	Real discount rate of 6%
(5) Value of additional gross income from wildlife-based land uses on mixed use farms in 2017 (N$)	**9,087,727**	**Calculation: (1)*(2)*(3)*(4)**

The assumptions adopted above would result in potential real benefits of around N$9.1m (discounted) in 2017. Aggregating these benefits over a 25 year period would subsequently result in total discounted benefits of N$120.9m (2015 prices). This should be seen only as a very broad first estimate of potential benefits due to a significant lack of data on this topic. It was not considered robust enough to include in the cost-benefit analysis and indeed, it would have had a negligible impact on the net outcome.

Other implicit assumptions are that the demand for hunting is not saturated by this growth in the number of hunting farms, and that the mixed-use farms would not affect the carrying capacity for the cattle on the same area of land. However there are also potential benefits that are not included in the calculation. This estimate does not include non-consumptive recreation values (i.e. photographic tourism); while this generally requires greater wildlife densities, such tourists are generally higher value in terms of the time and money spent in-country.

6.6 De-bushing

6.6.1 Volume of harvest

Zimmerman and Joubert (2002) estimate that across the ten bush encroached zones in Namibia, standing biomass of dry wood equivalent to 134.9 million tonnes could be utilised for charcoal production. Wood suitable for charcoal production should be between approximately 20mm and 150mm in diameter (Zimmerman and Joubert 2002, citing Galloway). We assume that wood of this size is also suitable for firewood and electricity production, the other key uses of biomass discussed in this report. Consequently, this study assumes that the 134.9 million tonnes represents the potential de-bushed/harvested volume, if the bush were 100% cleared across the entire bush-encroached area. Applying the key assumptions, this gives an estimate of 54.0 million tonnes of biomass that could be de-bushed initially. It is assumed that 5% of this total volume, or 2.7 million tonnes, could be de-bushed per annum.

Table 6.26: Estimated standing biomass of dry wood of appropriate size for charcoal in the ten bush-encroached areas of Namibia

Category of thickened bush			Total dry weight of standing wood of appropriate size for charcoal production (million tonnes)		
No. of area (map)	Main bush species	Bush density (avg. no. / ha)	Commercial land	Communal land	Total
1	Colophospermum mopane	2,500	8.7	17.9	26.6
2	Acacia reficiens	3,000	8.3	3.4	11.7
3	Acacia mellifera subsp. detine	2,000	1.3	0.1	1.4
4	Colophospermum mopane	4,000	7.6	17.1	24.7
5	Acacia mellifera subsp. detine	8,000	10.5	0.1	10.6
6	Acacia mellifera subsp. detine	4,000	21.3	1.7	23.0
7	Dichrostachys cinerea	10,000	9.4	4.6	14.0
8	Acacia mellifera subsp. detine	5,000	0.9	2.3	3.2
9	Termalia sericea	8,000	5.2	14.5	19.7
10	Rhigozum trichotomum	2,000	n/a	n/a	n/a
Total			**73.2**	**61.7**	**134.9**

Source: Zimmerman & Joubert 2002

Additional biomass could be harvested from the first and second follow-ups. We assume that usable biomass from aftercare treatments would be negligible. Table 6.27 shows production and cost factors of follow up and aftercare treatments as a factor of the production from and cost of the initial harvest from Honsbein et. al. (2009). It also shows the expected timing of these treatments.

Table 6.27: Production and cost factors and timing of follow up and aftercare treatments

Type of harvest	Timing (years after initial harvest)	Production factor (% of initial harvest)	Cost factor (% of initial harvest)
First follow up	5	55.0	50.0
Second follow up	10	30.3	12.5
First aftercare	20	10.0	23.3
Second aftercare	30	5.0	10.0

Source: Honsbein 2009

However studies indicate that the type and extent of de-bushing affects the nature of regrowth which can severely limit further exploitation. This needs to be further investigated to get a more accurate idea of future harvesting options, depending on bush species and locality. Furthermore, if a sustainable bush-harvesting strategy is pursued (i.e. allowing bushes to grow back in order to re-harvest rather than aiming for permanently lower bush densities), this would increase the long-run supply of biomass for utilisation. However, this would come at the detriment of livestock carrying capacities and groundwater recharge, and likely other benefits, such as tourism and biodiversity.

6.6.2 Cost of harvest

Five methods of mechanical de-bushing were included in the analysis, along with the use of arboricides. Only manually-applied arboricides were considered, as there is considerable uncertainty as to whether aerial arboricide application will be legal in Namibia in the future. 90% of de-bushing was assumed to be carried out manually while 10% was assumed to be carried out using arboricides.

The costs and capacities of the mechanical methods were taken from Beyond Bush's *Harvesting Namibian Encroacher Bush*. The number of operations using each harvesting method was assumed based on a balance between capacity and employment. Given the assumptions above, the estimated cost of de-bushing in 2016 (i.e. the first 787,770 hectares) would be N$1.89 billion (2015 prices, discounted). Over the 25-year horizon, this would be equal to a real cost of N$26.4 billion.

Table 6.28: Mechanical harvest methods

Harvest method	Capacity (tonnes p.a.)	Opex (N$/tonne)	Capex (N$)	Capital lifespan (years)	Employment (jobs p.a.)	Assumed operations (no.)[1]
Small scale, mostly manual	800	767	500,000	5	10	474
Light duty, semi-mechanised	1,400	666	1,300,000	5	10	235
Medium duty, fully-mechanised	6,000	408	9,000,000	10	16	112
Commercial scale, fully mechanised	8,000	324	13,500,000	10	14	56
Large commercial scale	20,000	480	23,000,000	10	12	30

1: for initial round of de-bushing

Source: de Wet 2015

The cost and capacity of arboricide use (specifically Bromocil) were taken from the Meat Board of Namibia (see Table 6.29). Given an average density of 5,022 bushes per hectare, weighted by land area (derived from Table 2.1), the cost for a density of 4,800 bushes per hectare was used. However, we do not have data on bush size so this is assuming that average bush size is 2m. To convert the cost per hectare into cost per tonne (to be consistent with the mechanical methods), the dry weight of biomass per hectare of land was calculated to be 5.14 tonnes/ha (from Table 2.1 and Table 6.26).

Multiplying the estimate of dry tonnes to be harvested per year, by the tonnes:hectares conversion, by the cost per hectare, results in an estimated cost of N$34.1 million (2015 prices, discounted) in 2016. Over the 25-year horizon, this would be equal to a real cost of N$415 million.

Table 6.29: Arboricides

Bromocil (800g active/kg)		Density (2m bushes/ha) 1600	3200	4800 [1]
Application rate	g/bush	0.625	0.625	0.625
	kg/ha	1.0	2.0	3.0
	kg active bromo/ha	0.8	1.6	2.4
Price	N$/kg	170	170	170
Chemical cost	N$/ha	170	339	509
Applicator	N$/ha	10	20	30
Labour	N$/day	50	50	50
	Treatment/ day	1.0	0.5	0.3
	N$/ha	50	100	150
TOTAL	N$/ha	230	459	689

1: extrapolated Source: Meat Board of Namibia

Arboricides can increase the cost of processing biomass, as it makes the wood harder and more difficult to chip. However, given the estimated gap between the amount of biomass that is harvested and the amount of biomass that Namibia can utilise, via firewood, charcoal production, and electricity generation, the use of arboricides could be a cost-effective way to thin areas of bush that will not be utilised.

The total discounted cost of de-bushing, using both mechanical methods and arboricide application under the assumptions discussed above, over the 25-year time horizon was estimated at **N$26.9 billion** (2015 prices). 98.5% of this cost is accounted for by the mechanical methods, even though they are only used for 90% of the harvest.

Chart 6.14: Amount of de-bushing by mechanical operations and arboricides

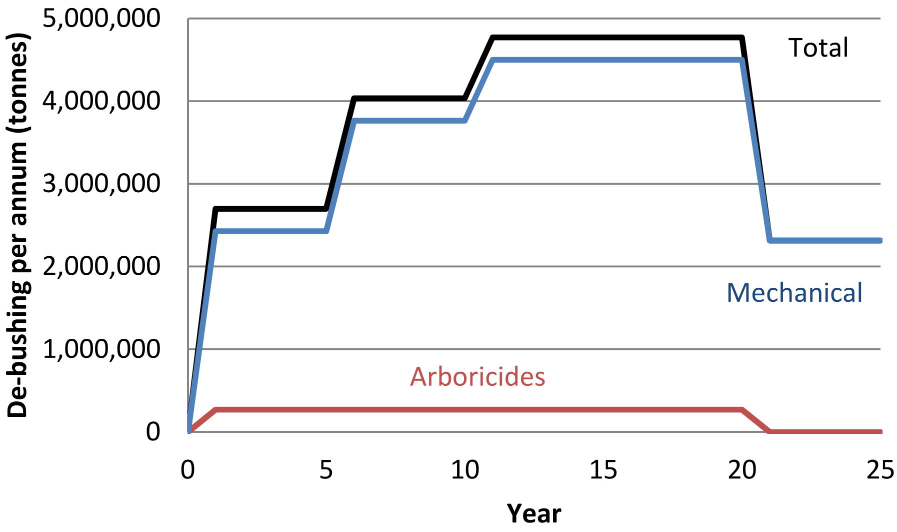
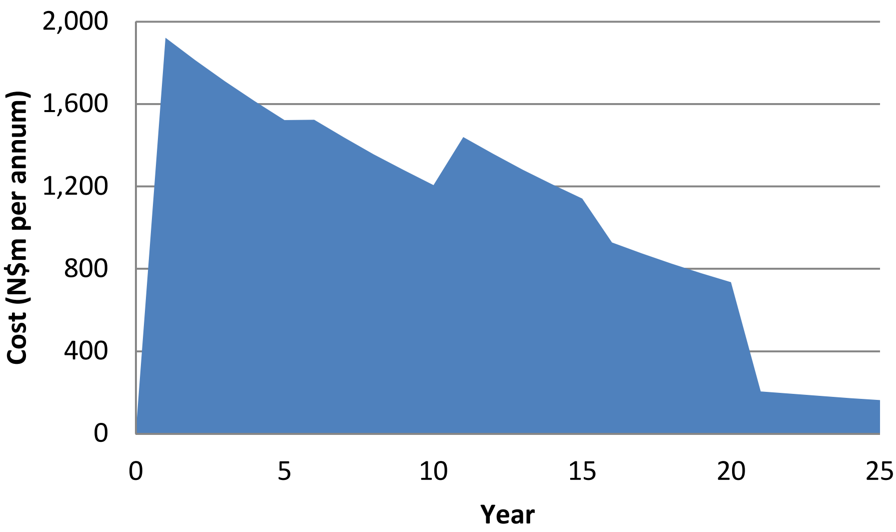


Chart 6.15: Cost of de-bushing



6.6.2.1 Sensitivity analysis

If the cost of de-bushing operations was 20% higher, the total real cost is estimated to increase by more than N$5 billion to N$32.2 billion (discounted). If the cost of de-bushing was 20% lower, perhaps due to economies of scale and optimisation of processes, then the total real discounted cost could be as low as N$21.5 billion.

Table 6.30: Sensitivity analysis for de-bushing costs

Scenario	Cost (N$m)[1]
Base case	26,856.4
Cost	
+20%	32,227.7
-20%	21,485.1

1: 2015 prices, discounted by 6% p.a.

6.6.2.2 Limitations and risks

The proportion of mechanical to arboricide methods (90:10) is a broad assumption, for which changes would have a significant effect on the total cost. However, if we assume that bushes treated with arboricides are not utilisable, or cost more to utilise, then there are ramifications in other sectors.

This study does not specify which methods should be used in which locations, depending on resources (e.g. labour), ecosystems and environmental context, bush species, and potential uses of the biomass. These should be investigated, as the costs and benefits could vary considerably by location depending on which methods are used.

There is a risk that not enough operations would be able to be mobilised to de-bush the targeted amount at the beginning of the programme. This would mean slower improvement in other sectors, such as livestock production and groundwater recharge, but it would not necessarily alter the costs of de-bushing.

6.6.3 Environmental costs

As well as the direct costs, de-bushing, whether by mechanical means or using arboricides, incurs environmental costs which we have not been able to quantify here. Further research should be carried out to ascertain the potential magnitude of these costs and they are an important consideration (see Sections 12.2.6, 12.2.16, and 12.2.17).

Mechanical methods involve cutting bushes down, removing the bush and its root system, or flattening bushes (in the case of rollers). Disturbance to the soil increases soil instability, leading to erosion and greater runoff. This could potentially constrain groundwater recharge even more than under conditions of bush encroachment. Harvesting bush also removes nutrients, such as carbon and potassium, from the system, which can represent a significant cost. The loss of soil organic carbon from de-bushing is quantified and valued in Section 6.4.

If bushes are cut above ground, some species' coppicing ability could mean that significant regrowth could occur quite quickly, worsening the bush encroachment problem. If bushes are cut below ground, regrowth is reduced, but it results in greater soil destabilisation and removes more nutrients from the environment. So there are pros and cons to different methods of harvest.

Small scale, mostly manual operations are likely to cause the smallest disturbance to the surrounding environment. They are highly selective and can minimise the soil area affected. However, it still involves the removal of nutrients from the soil and can contribute to soil instability.

Furthermore, transport of the chipper off-road can also damage the soil, organisms, and other plants.

The environmental costs are assumed to escalate as the size of the de-bushing operation increases. The light-duty, semi-mechanised operations use trolley saw trolleys which must be rolled along the ground, but their impact on the immediate surroundings of each bush that is cut is relatively confined. Medium-duty, fully-mechanised operations use excavators which are much heavier, causing greater disturbance to the ground they roll on. They are also less selective and affect a wider area around the targeted bushes.

The commercial-scale, fully-mechanised operation requires a bigger, heavier excavator and multiple tractors and trailers to transport the wood chips, as does the large commercial-scale operation, putting additional pressures on the soil, organisms, and other plants.

There remains uncertainty as to the full effects of arboricides on the environment. Arboricides can be toxic to animals, can accumulate in plants, soil, and water, and can travel through the ground, particularly in sandier soils, and be transmitted to non-encroacher bushes and trees. In these cases, they have the potential to impose severe environmental costs. However, arboricides are likely to be safely used in specific contexts, depending on factors such as soil type and bush species.

6.6.4 Social costs

There are also social costs to be considered with regard to de-bushing operations. If temporary workers are employed to de-bush on farms, this can pose some potential challenges. For example, one farmer who was interviewed chose to use aerial arboricides as their initial de-bushing strategy rather than employing workers to de-bush mechanically. This was partly due to concerns related to having a group of itinerant workers on their property, such as social disruption and potential poaching, as well as having to build or provide amenities for the workers.

Other social costs could include the spread of HIV-AIDS and other diseases, crime, and impacts on local services.

6.6.5 Employment costs and benefits

Employment is technically considered a cost in cost-benefit analysis. The labour costs of de-bushing are included in the analysis in Section 6.6.2. However, additional employment can also offer benefits, particularly in a country like Namibia where unemployment is incredibly high and youth employment is even higher. The social benefits of employment can include income security and higher living standards, improvements in health and education, decreased crime and drug use, decreased family disruption, and so on. There are also economic benefits via multiplier effects – the income that workers earn will be mostly spent within Namibia, stimulating economic activity.

It is estimated that under the assumptions of the above number of operations, the de-bushing programme could employ in excess of 10,000 people per annum during the initial round of de-bushing. This is only for the mechanical methods, as employment numbers for arboricide application are unknown. Additional jobs would also be provided during follow-ups. However, when the initial round of de-bushing is complete, there would be a significant fall in employment as the harvest volume drops.

The number of operations using each harvesting method was assumed based on a balance between capacity and employment. For the large commercial scale operation, 0.6 workers need to be employed for every 1,000 tonnes of harvest per annum. For small-scale, manual operations, the estimate is 12.5 workers.

7 Cost-benefit analysis

7.1 Central case

In the central case, the estimated discounted net benefits of de-bushing accrue to **N$48.0 billion** over 25 years (see Table 7.1). This is based on the central assumptions discussed in Section 6.

Table 7.1: Cost-benefit analysis – central case

Variable	Cost/benefit (N$m)[1]
Benefits	
Livestock	6,371.66
Groundwater	51,609.54
Utilisation	
Charcoal	4,060.59
Electricity	10,572.07
Firewood	1,186.17
Residual biomass	2,110.00
Carbon	
Offsets	227.88
Costs	
De-bushing	-26,856.42
Carbon	
Loss of SOC	-278.55
Livestock emissions	-982.01
Net benefit	**48,020.94**

1: 2015 prices, discounted

7.2 Scenario and sensitivity analysis

In this section, several key scenarios are explored to establish the range of costs, benefits, and net benefits that we can expect under different assumptions and outcomes. Furthermore, we observe how sensitive the NPV is to changes in key variables.

7.2.1 33% de-bushing

A key alternate scenario is a programme of de-bushing which only reduces bush density by 33%, rather than 67%. In this scenario, we estimate net benefits of **N$24.9 billion**, under the following assumptions, which differ from the central case:

- Carrying capacity increases by 50% (rather than 100%) which reduces groundwater used for livestock and emissions from livestock compared with the central case
- Groundwater recharge increases to 1.5% of rainfall (rather than 2%)
- Charcoal production is halved compared with the central case
- The capacity of electricity generation increases to 80MW by Year 13, rather than 170MW by Year 16 in the central case
- This correspondingly reduces the benefits from carbon offsets
- Firewood production is halved compared with the central case

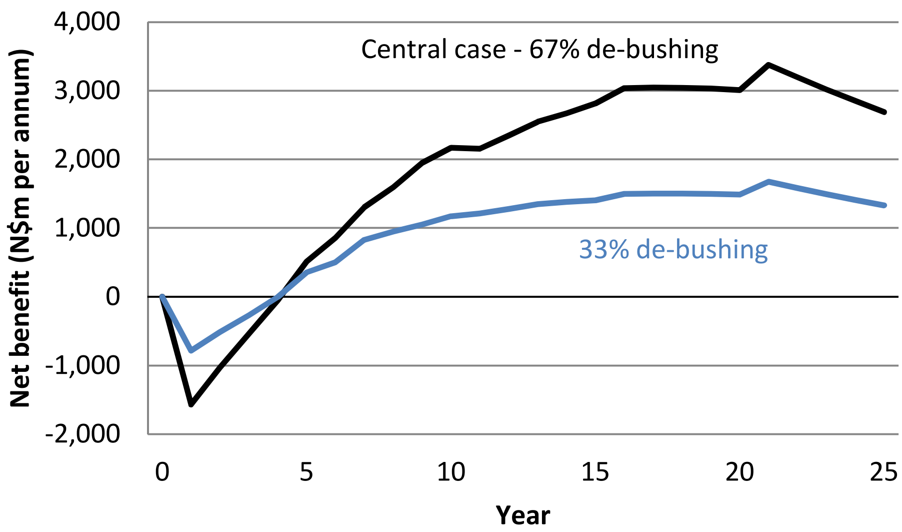
- Residual biomass is halved
- De-bushing costs are halved
- Loss of SOC is halved

Table 7.2: Cost-benefit analysis – de-bushing rate of 33%

Ecosystem service/ activity	Cost/benefit (N$m)[1]
Benefits	
Livestock	3,185.83
Groundwater	25,804.77
Utilisation	
Charcoal	2,030.30
Electricity	6,157.96
Firewood	593.09
Residual biomass	1,055.00
Carbon	
Offsets	132.70
Costs	
De-bushing	-13,428.21
Carbon	
Loss of SOC	-139.28
Livestock emissions	-491.01
Net benefit	**24,901.16**

1: 2015 prices, discounted

Chart 7.1: Costs and benefits at a 67% de-bushing rate and a 33% de-bushing rate



7.2.2 Best case scenario

In the best case scenario, we estimate that potential net benefits could be as high as **N$111.9 billion**. This is in line with the following assumptions, which differ from the central case:

- Carrying capacity increases by 200% (rather than 100%), but this increases groundwater used for livestock and emissions from livestock compared with the central case
- Groundwater recharge increases to 3% of rainfall (rather than 2%)
- Carbon is valued at N$60 per tonne as in the central case
- Charcoal production is the same as the central case (as the harvest of biomass does not increase), but the price is 20% higher
- The benefits from electricity generation are unchanged compared with the central case, as we believe that there is largely downside risk to this estimate
- This means that the benefits from carbon offsets are unchanged
- Firewood production is the same as the central case, but the price is 20% higher
- Residual biomass value is 20% higher
- De-bushing costs are 20% lower
- Loss of SOC is unchanged from the central case

Table 7.3: Cost-benefit analysis – best case scenario

Ecosystem service/ activity	Cost/benefit (N$m)[1]
Benefits	
Livestock	12,743.33
Groundwater	103,219.08
Utilisation	
Charcoal	4,872.71
Electricity	10,572.07
Firewood	1,423.41
Residual biomass	2,532.00
Carbon	
Offsets	227.88
Costs	
De-bushing	-21,485.13
Carbon	
Loss of SOC	-278.55
Livestock emissions	-1,964.02
Net benefit	**111,862.77**

1: 2015 prices, discounted

7.2.3 Worst case scenario

In the worst case scenario, we estimate that the potential net benefit could be as low as **N$28.9 billion**. This is in line with the following assumptions, which differ from the central case:

- Carrying capacity increases by 50% (rather than 100%), but this decreases groundwater used for livestock and emissions from livestock compared with the central case
- Groundwater recharge is unchanged from the central case, as this is already a very conservative estimate
- The SCC is used to value carbon

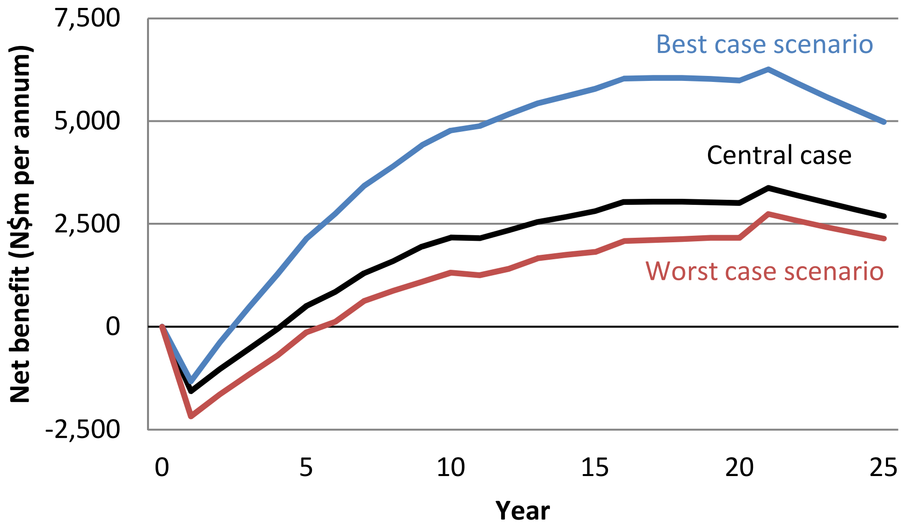
- Charcoal production is the same as the central case (as the harvest of biomass does not increase), but the price is 20% lower
- The capacity of electricity generation increases to 110MW by Year 19, rather than 170MW by Year 16 in the central case
- This means that the benefits from carbon offsets are lower
- Firewood production is the same as the central case, but the price is 20% lower
- Residual biomass volume is 10% rather than 15%
- De-bushing costs are 20% higher than in the central case

Table 7.4: Cost-benefit analysis – worst case scenario

Ecosystem service/ activity	Cost/benefit (N$m)[1]
Benefits	
Livestock	3,185.83
Groundwater	52,220.66
Utilisation	
Charcoal	3,248.48
Electricity	7,330.83
Firewood	948.94
Residual biomass	1,406.66
Carbon	
Offsets	1,340.88
Costs	
De-bushing	-32,227.70
Carbon	
Loss of SOC	-2,843.30
Livestock emissions	-5,688.76
Net benefit	**28,922.52**

1: 2015 prices, discounted

Chart 7.2: Costs and benefits in the central, best, and worst case scenario



7.2.4 Partial sensitivity analysis

Partial sensitivity analysis involves taking the central case and then varying a single assumption or estimate, while holding all others constant, to determine to the NPV's sensitivity to that specific variable. Variables which have a relatively insignificant effect on the NPV were not varied.

7.2.4.1 Livestock

If the carrying capacity was tripled rather than doubled, we could expect an extra N$4.2 billion dollars in benefits, despite increased costs from livestock emissions. If carrying capacity only increased by 50%, the NPV would likely fall by around N$2.1 billion.

7.2.4.2 Groundwater

Variation in groundwater recharge rates appears to have the most significant effect on the NPV. If it is assumed that recharge rates would increase from the current 1% to 3% of rainfall in bush-encroached zones, rather than 2%, the NPV would more than double to more than N$100 billion. We have not included a downside variation as 2% is already quite a conservative assumption.

7.2.4.3 Electricity generation

If the capacity of biomass power plants only reached 110MW, this would reduce the NPV by an estimated N$3.3 billion. This would be partly due to a reduction in the avoided cost of emissions.

7.2.4.4 Carbon treatment and values

As discussed in Section 6.4.2, carbon is valued in a number of ways. The SCC takes into account economic damages associated with a small increase in carbon dioxide (CO_2) emissions, and is much higher than any current market rate (US EPA, 2015). Using the SCC to value carbon, the NPV would fall by an estimated N$11.3 billion to N$36.8 billion.

However, if a market formed with carbon values closer to the SCC, this could represent an opportunity for Namibia to benefit. If other countries were willing to pay Namibia to produce lower levels of emissions than forecast (perhaps by leaving encroacher bush as is or not increasing stocking rates), then this may be a more profitable option. Although this doesn't look very likely in the near-term, over the longer-term it is a possibility.

As climate change is a globalised phenomenon, carbon emissions represent a global cost – emissions in Namibia do not have localised effects, but global effects, via higher atmospheric carbon dioxide concentrations. Therefore, if we are only considering the costs and benefits to Namibia in the analysis, then the costs and benefits associated with changes in carbon sequestration and emissions should be omitted. In this case, the NPV is increased by just over N$1 billion to N$49.1billion.

7.2.4.5 De-bushing cost

A 20% increase in de-bushing costs is estimated to reduce the NPV by N$5.4 billion while a 20% decrease is estimated to increase the NPV by the same amount.

Table 7.5: Partial sensitivity analysis

Varied ecosystem service/activity	Net benefit (N$m)[1]
Groundwater recharge	
3%	100,852.71
De-bushing costs	
-20%	53,392.22
Carrying capacity	
x3	52,188.36
Treatment of carbon	
Excluded	49,053.62
Central case	
	48,020.94
Carrying capacity	
x1.5	45,937.23
Electricity generation	
110MW	44,709.77
De-bushing costs	
+20%	42,649.65
Carbon value	
SCC	36,767.39

1: 2015 prices, discounted

7.2.5 Discount rates

One of the most important variables to undergo sensitivity analysis is the discount rate, as the choice of rate can be quite subjective and it can significantly impact the final outcome. In the central case, a real discount rate of 6% per annum was used. This is consistent with the real discount rate used in the Wildlife Resource Accounts of Namibia.

Table 7.6 shows how the NPV in the central case varies at discount rates ranging from 4% to 12%. The NPV is estimated at only **N$18.5 billion** at a discount rate of 12%, but at a discount rate of 4%, the NPV is estimated at **N$67.4 billion**. The net benefits tend to decrease as the discount rate rises because the benefits of de-bushing tend to be weighted towards the middle and end of the time horizon and are consequently more heavily discounted.

Table 7.6: Net present values at different discount rates

Discount rate (%)	Net benefit (N$m)[1]
4	67,384.76
6	**48,020.94**
8	34,619.21
12	18,505.21

1: 2015 prices, discounted

8 Policy recommendations

In the case of Namibia's bush encroachment, there are essentially two broad policy options available: to de-bush or not to de-bush. This study finds that a programme of de-bushing could generate an estimated net benefit of **N$48.0 billion** (2015 prices, discounted) over 25 years when compared with a scenario of no de-bushing. Sensitivity and scenario analysis indicate that the net benefit could range from **N$24.9 billion to N$111.9 billion**.

These results suggest that the net benefit of de-bushing, in the total economic value sense, would be significantly positive, and make a considerable contribution to Namibia's welfare. In addition, de-bushing operations could support an estimated **10,000 jobs per annum**. Furthermore, as we were only able to quantify and value a minority of the ecosystem services that would be impacted by de-bushing, and as we believe that many of the unquantified services would be positively affected by de-bushing, it is reasonable to believe that there is upside risk to our estimates.

It is estimated that de-bushing could generate benefits for livestock production, groundwater recharge, and tourism, charcoal and firewood production, and electricity generation, as well as carbon offsets for electricity. However, it would entail costs in the form of de-bushing operations, greenhouse gas emissions from livestock, and loss of soil organic carbon. In the central case, the total benefits for ecosystem services as a result of de-bushing are estimated at **N$76.1 billion** (2015 prices, discounted) over 25 years, while the total costs are estimated at **N$28.1 billion**. This results in an estimated net benefit of **N$48.0 billion**.

However, as this study is a total economic valuation, it does not take into account the investments required to unlock the potential benefits of de-bushing (e.g. purchase of additional livestock to utilise extra carrying capacity). Our analysis indicates that if these investment costs are less than N$48.0 billion, de-bushing would generate a positive Net Present Value (NPV).

We recommend a pilot programme of de-bushing with two main objectives: to reduce bush encroachment and to facilitate research and data collection. Research should focus on the effects of de-bushing on relevant ecosystem services that are currently unquantifiable or uncertain, the environmental impacts of de-bushing, and potential mitigation measures.

For example, as our analysis suggests, unlocking additional groundwater volumes would be a very valuable exercise, particularly in such a dry country as Namibia. Yet data on how groundwater recharge rates change with varying bush density is limited, as is research on the true price of water, specific to location and under scarcity (indeed, if water scarcity increases, the value of water will also increase). Further research, in conjunction with a pilot programme of de-bushing, would develop our understanding of this critical area and improve the accuracy of the model.

We have discussed the potential environmental costs of de-bushing operations but little progress been made in quantification and valuation. These potential costs could have a material impact on the outcome. For example, if de-bushing destabilises the soil, increasing erosion and runoff, this could further degrade the land rather than improve it. The decision to de-bush and the harvest method should be appropriate to each specific locality.

A notable risk of de-bushing is that increased stocking rates (in response to increased carrying capacity) could potentially lead to overgrazing, which would in turn encourage bush encroachment. Good rangeland management practices will be crucial in preventing a vicious cycle of bush encroachment, de-bushing, restocking, overgrazing, and back to bush encroachment.

We also recommend an analysis of the investment costs required to unlock ecosystem service benefits be undertaken. The key ecosystem services that were estimated to increase in value due to de-bushing were livestock production, groundwater recharge, tourism, and utilisation of biomass through charcoal and firewood production and electricity generation. All of these services will require capital investment in order to realise their potential benefits. For example, the purchase of cattle to utilise the additional carrying capacity, the purchase of game and investment in infrastructure to accommodate greater numbers of tourists, and the development of biomass power plants.

Some of these initiatives may require financial or fiscal intervention by the state. For example, it is estimated that the breakeven price for biomass-fuelled electricity generation would be N$2.00-N$2.20/kWh. This significantly exceeds the current tariff of around N$1.28/kWh, so a subsidy of N$0.72/kWh would be required for these plants to be feasible. However, if net national benefit is positive, the state's intervention is justified, and necessary to unlock the additional benefits of securing locally-generated energy supply. It should also be noted that the breakeven price for biomass-fuelled electricity generation is less than the breakeven price estimated for the Kudu power plant of N$2.55, so the subsidy required would be lower. Furthermore, if de-bushing is subsidised, this could reduce supply costs and therefore the breakeven rate.

There are likely significant differences in the net benefits of de-bushing across sectors and regions. Therefore, we recommend that the sector-specific and location-specific costs and benefits be investigated and that this can best be done in conjunction with the Integrated Regional Land-use Planning exercises carried out by the Ministry of Land Reform as well as the No Net Loss initiative led by the Ministry of Environment through its inter-ministerial Sustainable Land Management committee.

The sector-specific analysis should include a focus on the business case for each initiative to ascertain which would offer the best return. Economic multipliers and the social and economic benefits from the associated increase in employment could also be assessed for each initiative.

We believe that the complementarity between the sector approaches should also be explored in greater depth. In our analysis, we have estimated how additional stocking rates would affect groundwater extraction and emissions from livestock and how biomass-fuelled electricity generation would offset emissions from other sources (such as coal-fired plants), but there are multiple other linkages.

The location-specific analysis should be congruent with regional land use plans. Bush-encroached areas differ not only by land use, but also by bush species, other species, ecosystem, soil types, population pressures, proximity to markets, and other factors. These should all be taken into account when assessing the impacts of de-bushing.

In conclusion, our assessment of the economics of land degradation related to bush encroachment in Namibia indicates that de-bushing has the potential to generate substantial net benefits of around N$48 billion (in the total economic sense) over 25 years and thus contribute to Namibia's social welfare and economic growth. We recommend a pilot programme of de-bushing to begin to reduce bush encroachment and to facilitate additional research in order to gain a better understanding of all facets of de-bushing, its impacts, and its opportunities. We also recommend an analysis of the investment costs that would be involved. These actions will support more robust decision-making with regard to bush encroachment and de-bushing in the future.

9 Conclusion

This report presents an initial cost-benefit analysis of de-bushing in Namibia. Bush encroachment was delineated according to location and density and assessed in relation to political boundaries, ecosystems, land use, carrying capacity, and rainfall. Ecosystem services impacted by bush encroachment were identified and their likely direction of change in response to de-bushing was discussed. Key ecosystems services, for which there were adequate data, were quantified and valued to determine the costs and benefits that would be the result of de-bushing. These values were fed into a cost-benefit analysis to determine how the potential benefits of de-bushing measured up against the direct costs of de-bushing.

Bush encroachment has increased significantly in Namibia over past decades, largely as a result of habitat change. Overgrazing is thought to be a key driver of bush encroachment, but the displacement of browsers by livestock, the suppression of high intensity fires due to cattle farming, and increased atmospheric CO_2 concentrations are also likely contributors.

De-bushing was estimated to improve the value of ecosystem services such as livestock production, groundwater recharge, tourism, and biodiversity, as well as providing biomass for electricity production, firewood, and charcoal production, and construction materials and crafts. However, de-bushing is also likely to have some negative effects. Mechanical means of de-bushing can disrupt the soil and non-encroacher vegetation while chemical means have the potential to poison non-target vegetation and water sources. As bushes are a carbon sink, de-bushing may decrease the amount of carbon sequestered, in the soil as well as in the woody component. Furthermore, if cattle stocks are increased in response to de-bushing, this would increase greenhouse gas emissions.

In the central case, it was estimated that the net benefits of de-bushing would be N$48.0 billion (2015 prices, discounted) over 25 years. However, under varying assumptions and scenarios, net benefits ranged from N$24.9 billion, if the de-bushing rate was only 33%, to N$111.9 billion in a best case scenario. As we expect that many of the non-quantified services would likely benefit from de-bushing, there is upside risk to our estimates.

As this study involved a total economic valuation, it did not take into account the costs that would be necessary to unlock the potential benefits. For example, to utilise the increased livestock carrying capacity, additional cattle would have to be purchased. Therefore, it is recommended that further research and analysis be undertaken to provide decision-makers with a more comprehensive evaluation of all the associated benefits and costs. This would involve sector- and location-specific analysis, business case analysis, and more research into the impacts of de-bushing on ecosystem services.

Overall, we believe that de-bushing has the potential to generate substantial net benefits and contribute to Namibia's social welfare, warranting support and further investigation.

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11 Appendix I: the CICES

11.1 Provisioning services

Provisioning services are "*all nutritional, material and energetic outputs from living systems*". The nutritional and material divisions are disaggregated into groups that distinguish those arising from biological materials (biomass) and water, while for energetic outputs there is a distinction between biomass-based energy sources and mechanical energy. Table 3 illustrates the breakdown of provisioning services.

Table 3: Provisioning services in CICES

Division	Group	Class	*Examples*
Nutrition	Biomass	Cultivated crops	*Cereals, vegetables, fruits etc.*
		Reared animals and their outputs	*Meat, dairy products, honey etc.*
		Wild plants, algae and their outputs	*Wild berries, fruits*
		Wild animals and their outputs	*Game, fish*
		Plants and algae from in-situ aquaculture	*In situ seaweed farming*
		Animals from in-situ aquaculture	*In-situ farming of fish*
	Water	Surface water for drinking	*Collected precipitation for drinking*
		Ground water for drinking	*Freshwater abstracted from (non-fossil) groundwater layers for drinking*
Materials	Biomass	Fibres and other materials from plants, algae and animals for direct use or processing	*Wood, timber, skin which are not further processed; material for production e.g. devil's claw*
		Materials from plants, algae and animals for agricultural use	*Materials for fodder and fertilizer in agriculture and aquaculture*
		Genetic materials from all biota	*Genetic material (DNA) from wild plants, for biochemical industrial and pharmaceutical processes e.g. medicines*
	Water	Surface water for non-drinking purposes	*Collected precipitation for domestic, agricultural and/or industrial use*
		Ground water for non-drinking purposes	*Freshwater abstracted from (non-fossil) groundwater layers for domestic, agricultural and/or industrial use*
Energy	Biomass-based energy sources	Plant-based resources	*Wood fuel, straw for burning and energy production*
		Animal-based resources	*Fat, oils, from animals for burning and energy production*
	Mechanical energy	Animal-based energy	*Physical labour provided by animals*

11.2 Regulation and maintenance services

Regulation and maintenance services "*cover all the ways in which living organisms can mediate or moderate the ambient environment that affects human performance*". There are consequently three major divisions of regulation and maintenances services: the mediation of waste, toxics and other nuisances; the mediations of flows; and the maintenance of physical, chemical and biological conditions. The various groups and classes that relate to these divisions are presented in Table 4.

Table 4: Regulation and maintenance services in CICES

Division	Group	Class	*Examples*
Mediation of waste, toxics and other nuisances	Mediation by biota	Bio-remediation by micro-organisms, algae, plants, and animals	*Bio-chemical detoxification/decomposition/ mineralisation in land/soil, freshwater and marine systems*
		Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals	*Biological filtration/sequestration/storage/ accumulation of pollutants in land/soil*
	Mediation by ecosystems	Filtration/sequestration/storage/accumulation by ecosystems	*Bio-physicochemical filtration/sequestration/storage/accumulation of pollutants in land/soil*
		Dilution by atmosphere, freshwater and marine ecosystems	*Bio-physical-chemical dilution of fluids, wastewater in lakes, rivers, sea*
		Mediation of smell/noise/visual impacts	*Visual screening of transport corridors e.g. by trees*
Mediation of flows	Mass flows	Mass stabilisation and control of erosion rates	*Erosion protection*
		Buffering and attenuation of mass flows	*Transport and storage of sediment by rivers*
	Liquid flows	Hydrological cycle and water flow maintenance	*Capacity of maintaining baseline flows for water supply and discharge*
		Flood protection	*Flood protection by appropriate land coverage*
	Gaseous / air flows	Storm protection	*Natural or planted vegetation serving as shelter*
		Ventilation and transpiration	*Natural or planted vegetation that enables air ventilation*
Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	*Seed dispersal by insects, birds and other animals*
		Maintaining nursery populations and habitats	*Habitats for plant and animal nursery and reproduction*
	Pest and disease control	Pest control	*Pest and disease control e.g. invasive alien species*
		Disease control	*In cultivated and natural ecosystems and human populations*
	Soil formation and composition	Weathering processes	*Maintenance of bio-geochemical conditions of soils*
		Decomposition and fixing processes	*Maintenance of bio-geochemical conditions of soils by decomposition of dead organic material*
	Water conditions	Chemical condition of freshwaters	*Maintenance of chemical composition of freshwater column*
		Chemical condition of salt waters	*Maintenance of chemical composition of seawater column*
	Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	*Global climate regulation by greenhouse gas/carbon sequestration by terrestrial ecosystems*
		Micro and regional climate regulation	*Maintenance of rural and urban climate and air quality and regional precipitation/temperature patterns*

11.3 Cultural services

Cultural services "*cover all the non-material, and normally non-consumptive, outputs of ecosystems that affect physical and mental states of people*". The cultural category can be problematic as a result of the way the terminology is used; there is often not a clear distinction between services and benefits (see Section 2.2). Consequently CICES suggests that cultural services are primarily regarded as "*the physical settings, locations or situations that give rise to changes in the physical or mental states of people, and whose character are fundamentally dependent on living processes*".

Two divisions of cultural services are specified: physical and intellectual interactions with ecosystems and land-/seascapes; and spiritual, symbolic and other interactions with ecosystem and land-/seascapes. The detailed breakdown of cultural services is presented in Table 5.

Table 5: Cultural services in CICES

Division	Group	Class	*Examples*
Physical and intellectual interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Physical and experiential interactions	Experiential use of plants, animals and land-/seascapes in different environmental settings	*In-situ whale and bird watching, snorkelling, diving etc.*
		Physical use of land-/seascapes in different environmental settings	*Walking, hiking, climbing, recreational fishing (angling), recreational hunting*
	Intellectual and representative interactions	Scientific	*Subject matter for research*
		Educational	*Subject matter of education*
		Heritage, cultural	*Cultural heritage*
		Entertainment	*Ex-situ viewing/experience of natural world through different media*
		Aesthetic	*Sense of place, artistic representations of nature*
Spiritual, symbolic and other interactions with biota, ecosystems, and land-/seascapes [environmental settings]	Spiritual and/or emblematic	Symbolic	*Emblematic plants and animals e.g. Namibian Oryx, Welwitschia*
		Sacred and/or religious	*Spiritual identity; sacred plants and animals and their parts*
	Other cultural outputs	Existence	*Enjoyment provided by wild species, wilderness, ecosystems, land-/seascapes*
		Bequest	*Willingness to preserve plants, animals, ecosystems, land-/seascapes for the experience and use of future generations*

11.4 CICES, final ecosystem services and double-counting

CICES makes clear that it focuses on final ecosystem services, which as noted in Section 2.1 represent the point of interaction between humans and ecosystems. This distinction is important to avoid double-counting in the contribution of ecosystem services to benefits. Indeed, the SEEA-EEA recognises that "*ecosystem services…should be measured only when SNA or non-SNA benefits can be identified*".

However it is not necessarily possible to identify the benefits for each of the ecosystem services within the CICES framework. One example can be seen in the presence of separate provisioning ecosystem service classes of *reared animals and their outputs* (e.g. meat) and *surface water for non-drinking purposes* (e.g. water for livestock), where the latter can clearly represent an input to the former. Consequently the ultimate benefit derived from the provisioning service of water for livestock in this example is realised when it is used to produce meat, and taking them individually would double count the ultimate contribution of ecosystem services to benefits.

In order to avoid this issue of double-counting, the version of CICES adopted by SEEA is slightly different to that presented in this report. Instead of recognising the amount of meat or crops harvested as the ecosystem service with respect to reared animals or cultivated crops (the 'harvest approach'), it classifies as ecosystem services the flows related to nutrients, water and various regulating services (e.g. pollination) that contribute to their growth. The alternate version of CICES adopted by SEEA and a more detailed discussion can be found in SEEA-EEA p50.

Despite not being able to identify a direct and final contribution to a distinct benefit for each ecosystem service, this report maintains the full classification of CICES (as detailed in Table 3 – 5); it represents the most recent version of CICES and is appropriate for the purposes of developing an inventory of ecosystem services. The version presented in SEEA is conceptually significantly more complex, and it is not clear that the certainty of avoiding double-counting is worth this added complexity.

12 Appendix II: Ecosystem services – impacts of de-bushing

12.1 Provisioning

12.1.1 Cultivated crops

Bush encroachment theoretically reduces the available land for farming cultivated crops (e.g. maize, vegetables, sorghum, pearl millet, peanuts, sunflowers) or encroaches on fallow land, encouraging the opening of virgin land. In theory, it could also hamper growing conditions by increasing competition for water and nutrients at a landscape level. De-bushing for cultivation could therefore improve this service or offset other detrimental practices.

There is not enough data currently available to value the impact of de-bushing on crop production, but a methodology similar to that used for the valuation of livestock production (see below) could be used or an avoided loss value of opening up virgin land could be employed.

12.1.2 Reared animals and their outputs

Bush encroachment reduces available pasture land for livestock, particularly cattle, but also sheep and other livestock. It does this by restricting access for livestock and by reducing grass cover used for feed. Studies and anecdotal evidence suggest that current carrying capacities may be half of those experienced prior to severe bush encroachment. De-bushing should therefore increase carrying capacity.

12.1.3 Wild plants, algae and their outputs

Wild plants, often referred to in Namibia as Indigenous Natural Products (INP), can provide a source of food for humans (e.g. truffles, indigenous fruits such as marula and bird plum) and animals, including livestock (e.g. grasses, woody plants, indigenous fruits). They can also have medicinal uses (e.g. Devil's Claw).

With the exception of Mopane (which can be used for essential oils), bush encroachment likely has some opposing effects on this ecosystem service. The increased prevalence of certain woody plants comes at the expense of other trees and reduced grass cover. Dense bush could negatively impact the growth and harvest of wild plants, by reducing INP production through increasing competition for water, nutrients, and space and reducing harvest accessibility. De-bushing (up to a point) should therefore increase diversity, volume, and accessibility of INPs.

12.1.4 Wild animals and their outputs

While bush encroachment may reduce available land for wildlife, the switch to wildlife-based land uses (i.e. replacing cattle and other domesticated animals with game) could offset this to some extent, so the overall impact is unclear. It is therefore difficult to assess whether bush encroachment results in a net gain or loss of outputs such as game meat and skins. Browsers (e.g. goats, kudu, eland, dik dik, black rhino) can benefit from a certain degree of bush encroachment, which expands their food source. However, if bush is too dense and dominant, this could disadvantage browsers by restricting movement and access and reducing the variety of their food.

De-bushing that leaves a mosaic of habitats should therefore maximise wildlife diversity, numbers and accessibility. However, the lack of data and the uncertainty surrounding the net impact have prevented a robust valuation of this service. Section 6.5 offers a rough estimate of the scale of potential benefits from de-bushing in relation to hunting, by assessing the potential benefits from hunting operations.

12.1.5 Plants and algae from in-situ aquaculture

This service is not considered relevant to bush encroachment.

12.1.6 Animals from in-situ aquaculture

This service is not considered relevant to bush encroachment.

12.1.7 Surface water for drinking

Bush encroachment can negatively affect surface water by increasing siltation in rivers and dams via erosion, polluting surface water and reducing dam capacity. However, if de-bushing leads to increased stocking rates of animals such as cattle, this can also contribute to agricultural runoff and silting. If bush is so dense as to restrict accessibility to rivers or dams the flow of surface water for drinking may also be reduced. Investigation into specific areas where this may occur would be needed to determine the impact.

12.1.8 Ground water for drinking

Greater densities of bush increase the rate of evapotranspiration, reducing groundwater recharge rates. Bushes intercept some rainwater before it reaches the ground which then evaporates into the atmosphere. They also compete with grasses to take up significant amounts of water from the soil through their root systems. Transpiration, the process of water being carried from roots to leaves and evaporating, is where the main loss of water occurs. De-bushing would reduce the amount of water used by encroacher bushes, increasing recharge. Some studies suggest that recharge rates could increase up to eightfold (Christian et. al. 2010).

12.1.9 Fibres and other materials from plants, algae and animals for direct use or processing

Bush encroachment increases the biomass available to be used as materials for construction, such as poles, wood-cement bonded bricks or boards, and fibreboards. De-bushing would therefore increase the flow of this service. More data is needed on rate of use and prices of the different products to be able to value the overall use. Encroacher bush material could also be used for crafts, which could be valued using price of a representative unit. However studies indicate that the type and extent of de-bushing affects the nature of regrowth which can severely limit further exploitation.

12.1.10 Materials from plants, algae and animals for agricultural use

Bush encroachment increases the biomass available to be utilised as animal feed supplement. De-bushing would therefore increase the flow of this service, which may to a limited extent offset the grazing losses and livestock provisioning. However, for valuation purposes, this limited offset would be incorporated into the value of the meat produced from those animals fed the supplement and is not therefore calculated.

12.1.11 Genetic materials from all biota

Genetic material (DNA) from wild plants, algae and animals can be used for biochemical industrial and pharmaceutical processes and for bio-prospecting activities. If encroacher bushes dominate an area, this can reduce the species and genetic diversity of plants and animals, diminishing the availability and diversity of genetic material.

De-bushing could improve the stock of genetic materials if it is done in a way that rehabilitates the land and ecosystem back to its previous attributes.

12.1.12 Surface water for non-drinking purposes

Bush encroachment and the reduced basal cover that results can negatively affect surface water by increasing siltation in rivers and dams via erosion, polluting surface water and reducing dam capacity. De-bushing could alleviate this, however, if it leads to increased stocking rates of animals such as cattle, this could also contribute to agricultural runoff and silting. It should also be considered that certain types of de-bushing could create an initial erosion risk, with the subsequent impacts and environmental costs.

12.1.13 Ground water for non-drinking purposes

The flow and stock of this service would be impacted in the same way as the "ground water for drinking purposes" as discussed above. In the context of Namibia, bush encroachment and the consequent reduction in groundwater recharge can impact on industrial water provisioning as water is drawn across vast areas. For valuation purposes, however, the value of the amount of groundwater that was used in the production of agricultural products (e.g. watering cattle) is subtracted, as it is incorporated into the valuation of the production of these products (e.g. beef). Otherwise it would be double-counted.

12.1.14 Plant-based resources

Biomass from de-bushing has the potential to be utilised in several methods of energy production. De-bushing could therefore increase this service significantly.

Firewood is used widely as an energy source in rural and lower-socioeconomic urban areas, particularly for cooking. Wood chips are an input into charcoal production, which caters to both domestic and export demand. Wood chips can also be used as fuel for biomass power plants to generate electricity.

12.1.15 Animal-based resources

De-bushing could theoretically improve the amount of animal-based resources, such as fat, oil, carcasses, and dung, which are used for energy production, via increased carrying capacity. However, without an idea of the amount of production of these resources for energy production in Namibia, it is difficult to quantify the impact of bush encroachment or the change in value that would occur under a de-bushing scheme.

12.1.16 Animal-based energy

The use of donkeys and horses for the transport of people and goods is unlikely to be materially impacted by bush encroachment, unless there are cases where the bush is so dense as to restrict movement and accessibility.

12.2 Regulation and maintenance

12.2.1 Filtration/sequestration/storage/accumulation by micro-organisms, algae, plants, and animals

This service includes the biological filtration, sequestration, storage, and accumulation of pollutants in soil. The net impact of bush encroachment on this service is uncertain. If bush density restricts agriculture, reducing or eliminating the use of pesticides, it could relieve pressure on this service. If bush is cleared using arboricides, this could put pressure on the capacity of this service, as there is still uncertainty as to the full effects of arboricides on the immediate ecosystem.

12.2.2 Filtration/sequestration/storage/accumulation by ecosystems

This service includes the bio-physicochemical filtration, sequestration, storage, and accumulation of pollutants in soil. It is unknown how this is affected by bush encroachment.

12.2.3 Dilution by atmosphere, freshwater and marine ecosystems

It is unknown whether or how this service is affected by bush encroachment.

12.2.4 Mediation of smell/noise/visual impacts

Dense bush may have a positive impact by screening transport corridors, despite having perhaps a negative visual impact itself, for example for the purposes of game viewing or hunting. In the context of Namibia, this impact is at best limited.

12.2.5 Bio-remediation by micro-organisms, algae, plants, and animals

This service includes bio-chemical detoxification, decomposition, and mineralisation in land, freshwater and marine systems. More research needs to be done to determine whether and how bush encroachment affects this service.

12.2.6 Mass stabilisation and control of erosion rates

Bush encroachment tends to increase erosion rates. Grasses help stabilise the soil, preventing erosion, so when grass cover beneath the bush canopy is reduced due to encroachment, this can expose the soil to erosion. However, it is thought that some methods of de-bushing, particularly on more fragile soils, can also exacerbate erosion. Therefore, the choice of harvesting approach should take into account the risk of erosion. Selective harvesting and leaving sufficient bush coverage can reduce the risk of erosion from de-bushing. Furthermore, if stems and leaves are left on the ground rather than taken away after harvesting, they may help to reduce erosion.

More research is needed to determine the magnitude of the impact of bush encroachment, as well as de-bushing, on erosion rates, and how the impacts vary by harvesting scenario, ecosystem, land use, and soil type.

12.2.7 Buffering and attenuation of mass flows

Under conditions of bush encroachment, soil can form a hard crust (see below), creating high runoff regimes. De-bushing could negate this effect.

12.2.8 Hydrological cycle and water flow maintenance

Groundwater recharge is thought to suffer significantly under conditions of bush encroachment. As discussed above, as bush density rises, evapotranspiration rates also rise, reducing the amount of rainfall that reaches the deep soil and aquifers. Furthermore, if grass cover is reduced, exposing bare soil to rain and animals, this can cause soil crusting. The hard surface of the soil can then make it even more difficult for rain to infiltrate, reducing the retention capacity of water in soils and restricting groundwater recharge even further.

De-bushing has the potential to improve groundwater recharge rates by reducing the amount of evapotranspiration by bushes and assisting infiltration by increasing grass cover. However, if de-bushing further degrades the soil, there could be additional declines in groundwater recharge rates.

This is a key impact of bush encroachment that needs to be further researched. At this stage, we only have limited data from localised studies; this undermines the accuracy of the quantification, and also valuation, of the impact.

12.2.9 Flood protection

Bushes growing on riverbanks are thought to provide some degree of flood protection by stabilising the soil with their roots. De-bushing on riverbanks could therefore lead to a reduction in the quality of this ecosystem service, but as this is prohibited by law, it is not a significant concern.

Data and knowledge on the levels of flood protection that different densities of bush provide are currently lacking. In the future, the value of flood protection provided by bush encroachment could perhaps be estimated using the avoided cost method.

12.2.10 Storm protection

It is thought that bush encroachment has little material impact on storm protection.

12.2.11 Ventilation and transpiration

The services relating to ventilation and transpiration are generally not well understood in terms of their flows. However, it seems reasonable to assume that the increase in vegetation cover due to bush encroachment could enable higher rates of air ventilation. Consequently, de-bushing could have a negative impact on this service.

12.2.12 Pollination and seed dispersal

Under bush encroachment, less grass cover provides fewer seeds for dispersal. However, if perennial grasses are shielded from grazing by bushes, this may protect the seeds. Extracting significant quantities of bush for harvest can have a detrimental effect on seed dispersal due to the removal of nutrients and protection, but if stems and leaves are left on the ground after harvesting, they may help to trap grass seeds.

Not enough is known about how the diversity, distribution, and populations of pollinators, such as birds, bees and other insects, and other animals, are affected by bush encroachment.

12.2.13 Maintaining nursery populations and habitats

Bushes offer habitats, nesting places, protection, and food sources for arthropods, reptiles, birds, and small mammals. Thicker bush offers shelter and protection to smaller game (e.g. dik dik), but conversely, this makes it harder for predators to hunt successfully. De-bushing could therefore drive conflicting flows in this service, making it difficult to determine the net impact.

Valuation of this service is currently not possible, but measures of biodiversity and quantity of wildlife could be useful here to represent the quality of the habitat. The value would also be at least partly reflected in the value of tourism.

12.2.14 Pest control

Little is known about how or whether different bush densities affect pest control.

12.2.15 Disease control

Little is known about how or whether different bush densities affect disease control.

12.2.16 Weathering processes

A reduction in grass cover due to bush encroachment can leave the soil exposed to rain and animals, causing the surface of the soil to compact. The hard surface of the soil can then prevent rain from infiltrating, reducing the retention capacity of water in soils and making it even harder for grasses to re-establish. If de-bushing allows grasses to recover, this can improve the ecosystem's weathering processes. Leaving some biomass on the ground after harvesting can also help to protect the soil and assist restoration.

12.2.17 Decomposition and fixing processes

Some encroacher bushes, including *Acacia* species and *Dichrostachys cinerea*, are nitrogen fixers, and consequently contribute to soil fertility. Removing these bushes therefore represents a decline in soil nitrogen levels and other nutrients, which are locked up in the wood. This is one reason why so much of the literature on de-bushing emphasises the importance of leaving some of the biomass on the ground, so that these nutrients can be returned to the soil. The use of biochar, a by-product of charcoal production, to return carbon to the soil is also a promising mitigation measure.

It should be a research priority to gain a better understanding of how bush encroachment, de-bushing, and bush harvesting (including overharvesting) affect soil quality. This is incredibly important in the context of Namibia's largely arid, low quality soils, particularly in the most fragile regions.

The value of the expected improvement in the soil quality due to de-bushing would be partly reflected in the rise in the value of livestock production, given that this phenomenon is dependent upon the quality of the soil. The residual value is impossible to estimate based on the available data.

12.2.18 Chemical condition of freshwaters

Bush encroachment can negatively affect the chemical condition of freshwaters by increasing siltation in rivers and dams via erosion, polluting surface water. However, if de-bushing leads to increased stocking rates of animals such as cattle, this can also contribute to agricultural runoff and silting unless managed properly.

12.2.19 Chemical condition of salt waters

This service is not considered relevant to bush encroachment.

12.2.20 Global climate regulation by reduction of greenhouse gas concentrations

Bush encroachment and de-bushing have numerous, and often conflicting, effects on the flows of greenhouse gas emissions. The rise in woody biomass due to bush encroachment increases the amount of carbon sequestered in both the biomass and in the soil (soil organic carbon). However, as this tends to be accompanied by a decrease in grass cover, it is somewhat offset by a reduction in the carbon sequestered in grasses and their underground root systems.

De-bushing conversely leads to a reduction in the carbon sequestered in soil and in bushes in the short term (as the dead bushes decompose and release their carbon or as the biomass is burnt for energy production or clearing) and an increase in carbon sequestered in grasses over the longer term. Bush regrowth after the initial harvest also increases sequestration levels.

The livestock sector (particularly beef and cattle milk production) is a significant contributor to global GHG emissions, via factors including methane emissions from cows, dung fermentation, feed production, and transport of products. An increase in livestock production, enabled by an increase in carrying capacity due to lower bush density, would therefore be associated with an increase in greenhouse gas emissions in this sector.

12.2.21 Micro and regional climate regulation

Very little is known about how and by how much different bush densities affect climate, air quality, and regional precipitation and temperature patterns.

12.3 Cultural

12.3.1 Experiential use of plants, animals and land-/seascapes in different environmental settings

If wildlife viewing and landscape appreciation are undermined by dense bush, de-bushing can increase the value of this service by improving opportunities and success rates for wildlife viewing, increasing the diversity of species, and boosting the enjoyment that individuals gain from viewing wide, open landscapes which are symbolic of Namibia. This could have a positive effect on tourism in Namibia by attracting more visitors, increasing satisfaction levels, and raising revenue.

With regard to valuation, a revealed preference method, such as travel cost, could be used to estimate the change in willingness to pay pre- and post-de-bushing. Alternatively, a stated preference method, such as choice modelling, could also be used, with bush density as one of the variables. However, there are many costs to take into account (such as large capital investment costs or the costs of buying in wildlife for game parks) when estimating the overall impact of this which adds to the complexity of the valuation.

12.3.2 Physical use of land-/seascapes in different environmental settings

In addition to the negative impacts on wildlife viewing discussed above, dense bush can make activities such as hiking and hunting less appealing, by reducing the opportunity, success rates, and overall enjoyment of these activities. However, the relationship between bush encroachment and these tourism-centric activities is quite tenuous, and it would be hard to isolate the impact of de-bushing on these.

One approach to capture at least some of the value of the change in this service is to look at the benefits from a trophy hunting operation. However, the infrastructure that needs to be put in place to realise these benefits complicates the valuation. Section 6.5 offers a rough estimate of the scale of potential benefits from de-bushing in relation to tourism, by assessing the potential benefits from hunting operations.

12.3.3 Scientific

Scientific research services may be decreased by bush encroachment, due to reduced opportunities for research on topics such as cattle rearing and the ecology of natural rangelands. De-bushing could therefore improve this service. However, this service may also be increased by opportunities to study the ecological impacts of bush encroachment and methods of rehabilitating the land.

12.3.4 Educational

The impact of bush encroachment on education services is likely to be similar to that of scientific services.

12.3.5 Heritage, cultural

The heritage and cultural services associated with rangelands include certain ways of life and livelihoods, such as those of the San people. If their livelihoods were negatively impacted by bush encroachment, this would devalue the service. De-bushing could have a positive impact, but if it is not managed well and further degrades the soil, this could also be to the detriment of this service.

This service also includes the values of national and cultural identities. For example, Namibia's national anthem includes the line "Beloved land of savannas", highlighting the importance of the wide, open savanna to Namibians' identity. The quantification of this service is currently not very well understood.

12.3.6 Entertainment

De-bushing may increase the value of the ex-situ viewing or experience of Namibia's rangelands through different media (i.e. indirectly). For example, if de-bushing makes it easier to record video footage of wildlife and landscapes (perhaps increasing the stock and flow of video footage) both privately and for public broadcast, the value would increase. However, it is very difficult to measure symbolic value, which can overlap with other ecosystem services.

12.3.7 Aesthetic

A decrease in bush density would likely increase aesthetic appreciation, given Namibia's association with wide, open spaces and wildlife viewing. However, this change is difficult to measure. It could be valued using a revealed preference approach, such as the travel cost method, or a stated preference approach, such as choice modelling.

12.3.8 Symbolic

Some of the key features that individuals identify with Namibia include wide open spaces, wildlife viewing, and cattle rearing. De-bushing could improve all of these services. However, it is very difficult to measure symbolic value, which can overlap with other ecosystem services, such as existence value.

12.3.9 Sacred and/or religious

This ecosystem service provides value to individuals and communities through the ability to carry out sacred and religious practices. If de-bushing increases the carrying capacity of species such as eland, which are of sacred importance to the San, this could improve the value of this service.

It is very difficult to measure sacred or religious value.

12.3.10 Existence

Existence value is the value attached by individuals to the knowledge that the particular ecosystems and species continue to exist. Bush encroachment could have a negative impact on this service by reducing the prevalence of some species or eliminating ecosystem services such as the provision of meat and the keeping of cattle in some areas. De-bushing could therefore improve the value of this service.

This is a conceptual ecosystem service that is not well understood currently. Its value can only be ascertained via survey-based stated preference techniques.

12.3.11 Bequest

Bequest value is the value attached by individuals to the preservation of plants, animals, ecosystems, landscapes, and seascapes for the experience and use of future generations. Bush encroachment could have a negative impact on this service by reducing wildlife populations and diminishing the ability to keep cattle. De-bushing could therefore improve this service.

The quantification of this service is not well understood currently. As it has non-use value, a stated preference method, such as contingent valuation or choice modelling, must be used to elicit the value individuals place upon the future experience use of the ecosystems affected by bush encroachment.