The economics of landscape restoration: Benefits of controlling bush encroachment and invasive plant species in South Africa and Namibia

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The economics of landscape restoration: Benefits of controlling bush encroachment and invasive plant species in South Africa and Namibia

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ABSTRACT

Bush encroachment and alien plant invasions alter the composition and/or balance of species in natural ecosystems and impact biodiversity, land productivity and water availability. Therefore, the appropriate control and management of bush encroachment and alien plant invasions can restore ecosystems services and enhance the provision of timber and non-timber products to society. To understand the economics of land impacted by bush encroachment and alien plant invasions, we valued a selected number of ecosystem services from landscape restoration in South Africa and Namibia. In Namibia, the estimated value of ecosystem services from the restoration of bush encroachment was US$5.8 billion. In South Africa, the estimated value of ecosystem services from the restoration of bush encroachment was US$2.1 billion, and US$6.6 billion from the restoration of alien plant invasions. The most valued ecosystem service benefit assessed was water, followed by timber products and wood-fuels such as biomass to electricity, and then grazing. The value of these ecosystem services are considerable compared to the direct costs involved to clear invasive alien plants and control bush encroachment. This clearly illustrates that the management of invasive alien plants and bush encroachment can deliver significant ecosystem services benefits whose value outweighs the costs of restoration.

1. Introduction

Ecosystems deliver a wide range of benefits to society by providing, supporting and regulating services such as clean water, food and air (Costanza et al., 1997; De Groot et al., 2012). Despite the fact that all life depends on services derived from functional ecosystems, the Millennium Ecosystem Assessment (2005) revealed that over last 50 years approximately 60% of global ecosystem services have declined. In South Africa and Namibia, an important driver of ecosystem decline is bush encroachment and the spread of invasive alien plant species (Richardson, 1998, Richardson and Van Wilgen, 2004, Walker et al., 2004, Kraaij and Ward, 2006). Both bush encroachment and invasive alien plant species are known to compromise ecosystem function, and thereby reduce the ability to deliver a suite of ecosystem services that underpin economic productivity and sustainable development (Favretto et al., 2016; Reed et al., 2015).

Bush encroachment is the invasion and/or thickening of aggressive undesired woody species resulting in an imbalance of the grass to bush ratio, a decrease in biodiversity, and a decrease in carrying capacity (De Klerk, 2004). Bush encroachment has an estimated extent of 26–30 million hectares in Namibia, and 10–20 million hectares in South Africa (Bester, 1999; Kraaij and Ward, 2006). The encroachment of woody plants in southern Africa occurs mainly in the grasslands and savannas (Kreuter et al., 1999; De Klerk, 2004; Ward, 2005; Dougill et al., 2016). The dominant species responsible for this encroachment are: *Acacia mellifera, Acacia reficiens, Acacia tortilis, Acacia nilotica, Acacia karoo, Dichrostachys cinera, Termanalia sericia, Rhigozum trichotomum and Tarchonanthus camphoratus* (Kraaij and Ward,

Abbreviations: N$, Namibian dollars; US$, US dollars; ZAR, South African Rand; t, metric tonnes. All biomass expressed on a dry mass basis; ha, hectares. 1 ha=0.01 km^2; CO_{2eq}, greenhouse gas emission in carbon dioxide equivalents

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2006). In the most severely encroached areas, up to 75% of the surface can be occupied by a single bush species (De Klerk, 2004) resulting in impenetrable thickets that suppresses the growth of the understory grasses, and excludes game and cattle from ranging. Together with increased water use, this results in a loss in carrying capacity and productive use of rangelands for both cattle and game. This threatens the livelihood of both commercial and communal game and livestock ranchers (Condon, 1986; Dean and Macdonald, 1994, O'Connor et al. 2014). Bush encroachment is driven by the mismanagement of rangelands- through overgrazing, the suppression of bushfires, and the exclusion of some browsing game species. In addition, the increasing carbon dioxide concentrations in the atmosphere are favouring the growth of woody biomass and bush encroachment (Bond and Midgley, 2012, De Klerk, 2004; Ward, 2005; Walker et al., 2004).

Biological invasions involve the introduction, establishment and spread of alien species into areas where they do not occur naturally. Biological invasions threaten biodiversity and ecosystem functioning. Many species from different taxonomic groups have been introduced to support industries such as agriculture, forestry, mariculture, horticulture and recreation which can contribute to economic development (Sharma et al., 2010). Biological invasions are increasing due to human-mediated disturbance of land and soil, global changes in climate and biogeochemical cycling, and an increased dissemination of propagules from growing global trade, transportation and migration (Le Maitre et al., 2000, 2004). Of the estimated 9000 plant species introduced to South Africa, 198 are currently classified as being invasive (Working for Water, 2016). The main woody invasive alien plant species were part of large afforestation programs in the past and include various *Acacia*, *Eucalyptus*, and *Pinus* species (Richardson, 1998). The ecosystems in higher rainfall regions harbour the majority of alien plant invasions (Le Maitre et al., 2000; Van Wilgen et al., 2008); while in drier regions the invasions are limited mainly to *Prosopis* spp. (mesquite) in the alluvial watercourse and plains (Harper-Simmonds et. al. 2015; Tree Altas). Many of these species have spread and proliferated from plantations to become invasive in the adjacent landscape, or were from large scale introductions of invader species in the late 1800 s aimed at stabilising sand dunes (Hobbs, 1988; Noble, 1989; Richardson and Cowling, 1992; Richardson and Van Wilgen, 2004; van Wilgen et al. 2001). The impacts of invasive alien plants on South Africa's terrestrial and freshwater ecosystems have long been recognised and led to the Department of Environmental Affairs establishing the Working for Water programme in 1995 (Richardson, 1998; Van Wilgen et al., 2008). Since then, significant progress has been made in the clearing of invasive alien plants, and the programmes have expanded to address the various threats to the productive use of land and water, and the functioning of natural systems from invasive alien species, wildfires and land degradation. In doing this work, they help ensure meaningful livelihoods for those employed from marginalised communities and develop opportunities for value added industries (DEA-NRM, 2015). However, to date, relatively little cost recovery has been obtained in these restoration programmes in the form of payment for ecosystem services restored, nor from the value adding opportunities of using woody biomass for timber products, wood fuels and electricity.

Since both bush encroachment and alien plant invasions alter the composition and/or balance of species in natural ecosystems, they cause land degradation and denudation with a loss of ecosystem services. Land restoration requires the appropriate management of bush encroachment and alien plant invasions with remedial action involving control, containment, and eradication (Reed et al., 2015). In order to increase our understanding of the economics of landscape restoration in Namibia and South African, we estimate the value of the benefits from key ecosystem services (water availability, grazing capacity, carbon, timber, wood fuels and electricity) that are provided through the appropriate management of bush encroachment and invasive alien plants.

2. Methodology

The research methodology used in this study followed the 6+1 approach of the United Nations Convention to Combat Desertification (UNCCD) Economics of Land Degradation (ELD) Initiative, which establishes a common approach for determining robust cost-benefit analysis to inform decision-making processes (ELD, 2015a). The key steps of inception, geographical characteristics, types of ecosystems and valuation used to guide this research were: -

2.1. Inception and geographical characteristics

The inception of the study was driven by the need to understand the extent of bush encroachment and plant invasions and impacts on ecosystem services. This required the mapping of bush encroachment and alien plant invasions. Bush encroachment affects an estimated 26–30 million hectares of land in Namibia, covering eleven of the fourteen political regions of Namibia. 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, the bush densities tend to increase (Honsbein et. al. 2009). From a number of surveys and field studies conducted over several years, the spatial extent of bush-encroached zones in Namibia has been produced (Bester, 1999). Information on the plant species in these bush-encroached zones were used to determine the biomass of bush encroachment (Birch et al. 2016).

In South Africa, bush encroachment was identified on untransformed areas (cultivated areas or those used for plantation forestry were excluded from the analysis) using land cover data (SANBI BGIS, 2010 LandCover). Areas of encroachment were defined as those where the percentage woody thickening was $>20\%$. We also limited our analysis to the arid savannas (rainfall <680 mm) as above this threshold it is possible to get closed canopy formations naturally and this would be difficult to distinguish from bush encroachment (Sankaran, 2005).

The extent of invasive alien plants in South Africa was extracted from the National Invasive Alien Plant Survey (NIAPS) which mapped the condensed hectare coverage of 27 alien plant taxa (Kotzé et al., 2010). Aerial surveys were conducted across tertiary catchments to estimate the spatial distribution or density of woody biomass for the alien plant invaders. Most of the Northern Cape was not included in NIAPS study, although recent estimates of *Prosopis* invasions in this province are estimated to be 1.48 million hectares in extent (0.36 million condensed hectares, Vanden Berg 2010). The biomass from plant invasions was estimated from geospatial mapping data (Kotzé et al. 2010); using the extent and density of the invasive alien plants (Le Maitre 2000 and unpublished). Only the main woody ($>20\%$ lignin) tree species were considered- *Pinus, Acacia, Eucalyptus, Hackea, Prosopis and Poplar* spp. Namibia does not have extensive plant invasions, or is not monitoring and reporting on them, and therefore could not be mapped.

2.2. Ecosystem services and economic valuation

Literature reviews and the expert knowledge of stakeholders were used to understand the key types of ecosystem services affected by bush encroachment and plant invasions. This identified several provisioning services (water availability, wood materials, wood fuels and electricity, and grazing capacity) and a regulating service (ecosystem carbon) that were considered as the ecosystem services impacted by bush encroachment and plant invasions, and therefore important to value. Many other provisioning, regulating, cultural and habitat ecosystem services were not valued. This study is therefore a partial economic assessment of key benefits from landscape restoration that can contribute to an assessment of the total economic value of invasive alien plant and bush encroachment management (Total Economic Valuation framework;

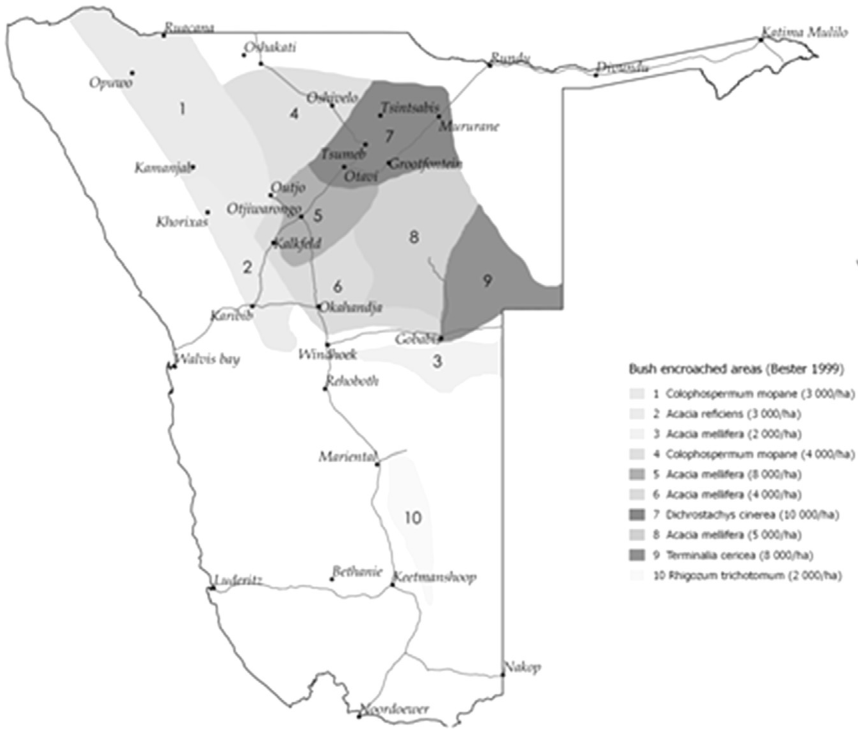

Fig. 1. The extent of bush encroachment in Namibia (Bester, 1999).

Merlo and Croitoru, 2005). In addition, the direct costs of controlling bush encroachment and clearing plant invasions were quantified to determine if the cost of action can outweigh the benefits from these ecosystem services. However, this study did not quantify other costs, such as the investment that would be necessary to unlock these potential benefits (e.g. purchase of additional livestock) or the ongoing land maintenance that may be needed in the future. The valuation assumed a business-as-usual scenario of existing action, and a restoration scenario where invasive plants are removed and the density of bush encroachment reduced.

The following general assumptions were made.

Both Namibia and South Africa:

- Time horizon of 25 years was used to calculate the net present value
- Real prices in Namibian dollars or South African Rands (base year 2015) were used with a discount rate of 6% per annum and converted to US dollars (US$) at the average spot rate for 2015 (1 US$=ZAR12.77 and 1 US$=N$12.77)
- Namibia only:
- 60% of the identified bush-encroached areas are restored
- In these areas, restoration to reduce the encroacher bush density by up to 67% in order to attain a 33% average density
- 5% of the targeted bush-encroached land to be de-bushed per annum
- South Africa only:
- 90% of bush-encroached areas and 80% of areas invaded by alien plants are restored
- In bush encroached areas, restoration will reduce the encroacher bush density by up to 67% in order to attain a 33% average density; while 100% of the invasive alien plants should be cleared during restoration.
- 5% of the targeted bush-encroached land to be de-bushed per annum.

To value the timber, wood fuels and electricity that can be provided through the appropriate management and control of bush encroachment and invasive alien plants, biomass availability was estimated and attributed to a suitable market use and value. The woody biomass of plant invasions varies from 32 to 198 t/ha (Mugido et al., 2014; Van Laar and Theron, 2004; Le Maitre et al. 2000; Le Maitre et al., 2001). It was assumed that only 80% of this standing stock of biomass is actually available for value-adding, due to slope and other factors that limit access to the biomass that would incur substantial additional costs in harvesting. Since both invasive alien plants and bush encroachment represent an undesirable state, the clearing of plant invasions and thinning of bush is considered as a step to restore a desired state of productive land and healthy ecosystems. As a consequence, opportunities for continuous local supplies of these biomass resources are not considered in order to ensure local eradication (extirpation) of invasive plants and the control of bush encroachment, with the goal of ecosystem restoration. The woody biomass available for utilisation is therefore the total standing stock of woody biomass resource, harvested and utilised over a defined time period. For alien plant invasions plants, 100% of the standing stock is available since the objective is eradication and clear-felling. For bush encroachment, an estimated 67% is considered available through a process of bush thinning since the desired end state is a 30–40% tree cover of the arid (< 450 mm year rainfall) savanna and grasslands (Sankaran et al., 2005; Ward, 2005). However, these biomass estimates did not include the spread of bush encroachment and plant invasions that may be as much as 5–10% per annum. The availability of the estimated biomass stocks was determined over a 25 year time period, as this was deemed a feasible time period restore landscapes and could coincide with the predicted lifetime of the technology and the infrastructure requirements of value adding industries. A 5 year lag for implementation was assumed, together with an appropriate production cycle lifetime.

3. Results

3.1. Biomass from bush encroachment and invasive alien plants

Based on the extent of bush encroachment (Fig. 1), it was estimated that the total biomass available from bush thinning in Namibia is 54.0 million tonnes (Zimmermann and Joubert, 2002), and could be harvested at a rate of 2.7 million tonnes per annum.

In South Africa invasive alien plants cover about 10 million ha of the country (8.28% of land area at average density of 17%). If the invaded area was adjusted to represent 100% cover or density, then the equivalent of 1.7 million 'condensed hectares' are covered by woody invasive alien plants (Le Maitre et al., 2000; Kotzé et al. 2010). Invasions by alien tree of *Acacia spp*., cover an estimated condensed area of more than 0.4 million ha, more than 30% of the total condensed area, with the next most extensive being trees of *Eucalyptus* spp.(0.25 million ha) and *Pinus* spp. (0.12 million ha). The distribution of these plant invasions, together with information of yields of biomass per unit area from forestry and field studies of plant invasions, was used to estimate the total woody biomass from the 10 million hectares of land invaded to be 167 million tonnes. A similar approach was used to estimate biomass of bush encroachment in South Africa. The land area affected by bush encroached has been estimated at 10–20 million ha (Kraaij and Ward, 2006). We have excluded bush densities < 20% as these cannot be considered bush encroachment, and we have limited the analysis to the arid savannas, as the higher rainfall areas can naturally form dense bush, coastal thicket and forest. The extent of bush encroachment was estimated at 8 million hectares of land. Assuming a total biomass of 4, 8 and 12 t/ha for areas of light, medium and dense encroachment; we estimated the total biomass of bush encroachment in South Africa to be 58 million tonnes (Fig. 2).

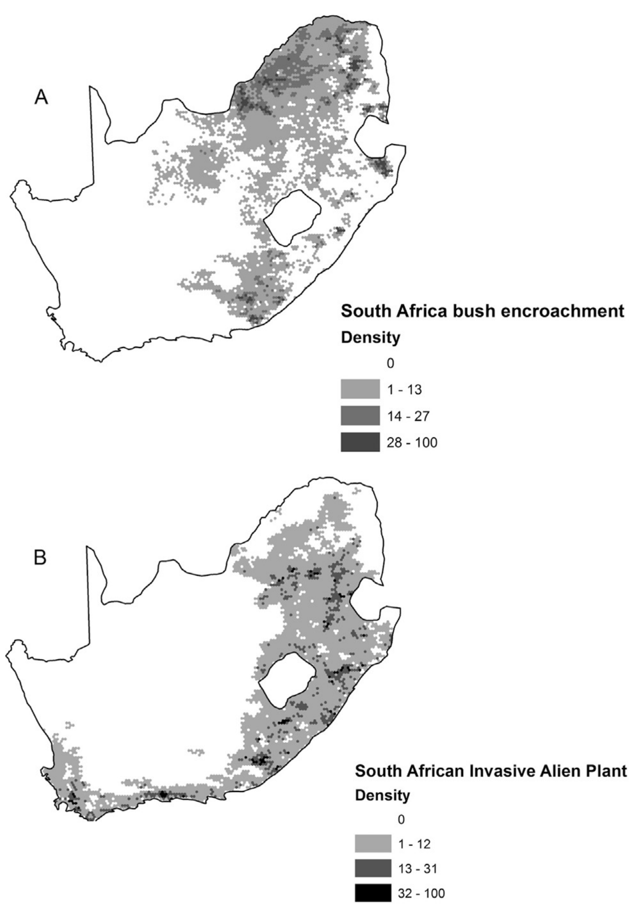

Fig. 2. The extent and density (t/ha) of woody plants from alien plant invasions and bush encroachment. A-bush encroachment in South Africa and B- invasive alien plant invasions and in South Africa (excludes the plant invasions of the Northern Cape).

3.2. Assessment of ecosystem services from the clearing of plant invasions and control of bush encroachment

3.2.1. Water resources

The impacts of invasive alien plants on water resources in South Africa have been well studied and modelled, with biomass growth curves which relate water use to plant age (tall shrub, medium tree and tall tree), and the vegetation type (Le Maitre et al., 2000, 2004, Richardson and Van Wilgen, 2004). There is also data on reductions in streamflow at the landscape scale from catchment experiments which compared the streamflow under natural vegetation and that under commercial plantations (Dye, 1996; Scott et al. 1998; Van Lill et al., 1980). This has enabled assessments of the increased water streamflow from the removal and control of invasive alien plants at the level of primary catchment, with the incremental water use quantified in terms of the changes in the mean annual runoff due to invasive alien plants compared to the natural vegetation type of that eco-region. The incremental water use has been estimated at 3 303 million m^3 per year (or 6.67% of the mean annual runoff, MAR) for South Africa's alien plant invasions (Le Maitre et al., 2000). A similar approach carried for bush encroachment estimated the incremental water use of estimated to be 832 million m^3 of water per annum. This assumed that bush encroachment water use is 40% less than alien plant invasions (due to the fact that bush encroachment is predominantly found in arid savannas and grasslands), and that bush thinning will be carried out to harvest 67% of biomass in for restoration of the savanna and grassland systems. The incremental water from land restoration in South Africa was valued using the tier-1 water resource management charge (ZAR1.50/m^3, Blignaut et al., 2008).

In Namibia, the main impact on water resources was assessed by overlaying a map of average rainfall distribution with the map of the location and density of bush encroachment, to determine rainfall in the bush-encroached areas. Assuming an average groundwater recharge rate across the entire country of 1% of the rainfall (Christellis et al., 2011; Christian et. al. 2010), just over 600 million m^3 per annum is estimated to be used by bush encroachment. An avoided cost approach was used to estimate the value of this additional recharge of ground water following bush thinning. Data from NamWater (2015) revealed that a project in Kalkfeld to increase capacity by 300 m^3 per day would incur capital costs of around N$64.6 million (in 2015 prices) over its 30 year lifetime. 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$14.7/$m^3$ of water. The value of this incremental water made available from the control of bush encroachment and clearing of plant invasions for South Africa and Namibia is summarised in Table 2.

3.2.2. Grazing capacity

In South Africa, several livestock are kept in both communal and commercial animal husbandry systems. A total of 13.915 million cattle, 24.486 million sheep and 6.134 million goats are part of animal husbandry (2014/2015) (Table 1). This is equivalent to 19.059 million Large Stock Unit, LSU (LSU: Cattle=1, Sheep=0.17, Goats=0.16; van Oudtshoorn, 2007, Meissner, 1982, 1983).

These 19.1 million LSU occupy grazing lands to the order of 83.9 million hectares in the various provinces, and this represents an average livestock land footprint of 4.4 ha/LSU (Morgenthal et al., 2004). Additional grazing capacity that can be provided through the control and eradication of invasive alien plants and bush encroachment in South Africa was determined by estimating the area impacted by bush encroachment and invasive alien plants in the various provinces, the grazing capacity of the region and the available land in each

Table 1
Animal husbandry and grazing area in South Africa with carrying capacity per province (ha/LSU).

Province	Total grazing area (ha)	Animal husbandry numbers *1000			LSU*1000	ha/LSU
		Cattle	Sheep	Goats		
Western Cape	9,105,821	563	2 897	223	1091	8.3
Northern Cape	29,089,367	501	6 174	511	1632	17.8
Free State	7,538,677	2 308	4 747	240	3153	2.4
Eastern Cape	13,644,822	3 305	7 056	2 320	4875	2.8
Kwazulu Natal	5,329,640	2 776	752	822	3035	1.8
Mpumalanga	3,243,931	1 436	1 815	89	1758	1.8
Limpopo	8,847,848	1 048	260	1 185	1281	6.9
Gauteng	390,000	249	97	41	272	1.4
North West	6,738,014	1 729	688	703	1958	3.4
Total	**83,928,120**	**13,915**	**24,486**	**6,134**	**19,059**	**4.4**

province (see Table 1). The value of the additional grazing capacity (provided through the clearing invasive alien plants and control of bush encroachment) was determined using an average animal husbandry production data- a production cycle of 21 months for cattle and 29 months for sheep/goats, with a LSU of 450 kg for cattle and a SSU of 77 kg for sheep and 76 kg for goats. Although there is evidence that an increase in bush encroachment disproportionately decreases grazing capacity (Harmse et al., 2013; and Richter et al., 2001), Therefore, we have taken a conservative approach by assuming a proportionate increase in grazing following bush thinning and assumed that only 60% of the expected grazing capacity will be realised since bush encroachment occurs in areas with a lower than average livestock carrying capacity. The additional grazing potential was estimated to be: (i) 159,892 sheep, 53,297 goats, and 64,870 cattle after bush thinning and (ii) 375,108 sheep, 125,035 goats and 152,185 cattle after clearing alien plant invasions. Livestock was valued at market prices per head, assuming an auction weight of 220 kg for cattle and 40 kg for sheep and goats (Landbou, 2014).

The valuation of grazing capacity following the control of bush encroachment in Namibia focussed on cattle, because it is the dominant livestock production system in the bush-encroached zones. Based on literature reviews and expert knowledge, a reduction in bush density by two-thirds would at least double carrying capacity after a four year lag. Livestock census data was used to estimate head of cattle in each of the ten bush-encroached areas (Directorate of Veterinary Services, 2015) and the additional grazing capacity that could be gained from bush thinning. A weight of 246.9 kg/head and the 2015 average beef producer market price of N$27.3/kg were used to estimate the value of additional grazing capacity generated from the control of bush encroachment (FAO, 2015). The value of additional grazing capacity from control of bush encroachment and clearing of plant invasions for South Africa and Namibia are summarised in Table 2.

3.2.3. Wood products, wood fuels and electricity

Due to the diversity of energy and material products that can be generated from trees, we focussed on value added industries with appropriate, feasible and mature technologies that can readily generate marketable products from the available woody biomass resource. Typically, merchantable timber is 10% of the total biomass of natural forests (Forestry Handbook, 2012). However, for invasive alien plants and bush, this is further reduced because: (i) several species are bushes and not tall trees and are unsuitable for timber (ii) many invasive alien plant and bush encroaching species are growing outside their optimal eco-climatic zone and therefore have sub-optimal productivity (iii) the fire regimes in many vegetation types of South Africa are shorter than the 15–20 year tree age required for optimal timber production and (iv) some invasive alien plant species are under active biocontrol programmes, which limits their growth and reproductive ability. Therefore, the available timber that requires specific characteristics of the biomass (such large stem diameter of tree for timber) is reduced in invasive alien plant and bush encroached stands- to an estimated 1.5% and 0.5%, respectively. This means that the remaining biomass is available for lower value products; such as: poles and fence-posts, firewood, charcoal, and the generation of electricity. The proportions of products that can be produced from these resources were determined from the above considerations, as well as data on the biomass species present and their suitability for various products (materials and

Table 2
Economic Value of ecosystem service benefits from restoring land impacted by plant invasions and bush encroachment in Namibia and South Africa.

Economic value of ecosystem service from the restoration of land impacted bush encroachment in Namibia (million US$)*

Namibia: bush encroachment	Water	Grazing	Carbon[a]	Wood products and energy		
				Charcoal	Firewood	Electricity
	4041.4	499.0	17.8	318.0	92.9	827.9

Economic value of ecosystem service from the restoration of land impacted by bush encroachment and invasive alien plants in South Africa (million US$)*

South Africa: bush encroachment	Water	Grazing	Carbon[a]	Wood products and energy			
				Timber	Poles	Wood fuels	Electricity
	582.6	55.8	149.4	14.0	21.1	560.2	702.9

South Africa: invasive alien plants	Water	Grazing	Carbon	Wood products and energy			
				Timber	Poles	Wood fuels	Electricity
	2313.0	131.0	641.1	180.0	90.6	233.6	3020.8

* Net present value with 6% discount rate over a 25 year period.
[a] Land use change and land-use practice not included

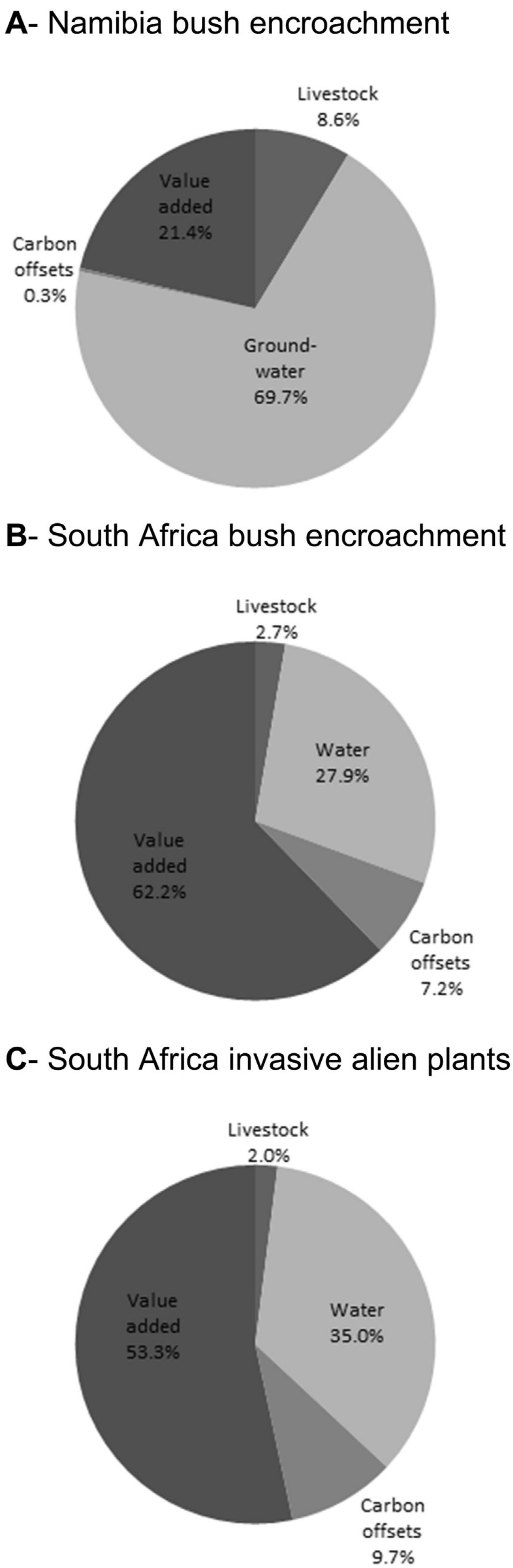

Fig. 3. Economic value of key provisioning ecosystem services from landscape restoration in Namibia and South Africa. Value of ecosystem services as expressed as a percentage of the total, using the net present value with 6% discount rate over a 25 year period.

energy). Market values of products were used to determine the total economic value of these biomass-related provisioning services. In addition, the suitability of various wood products from the particular tree species and tree maturity was considered. Based on the known tree species of alien plant invasions and bush encroachment, we estimated the utilisable biomass by considering various timber and non-timber products from both the invasive alien plant and bush encroachment resources in Namibia and South Africa (UNECE- FAO, 2014).

In South Africa, for the woody invasive alien plants there is 167 million tonnes woody biomass available, which can provide (% of total biomass): 1.5% timber, 3% poles, 32.5% firewood and charcoal, 53% electricity, and 10% residues. For bush encroachment in South Africa 58 million tonnes of oven dry biomass can provide (% of total biomass): 0.5% timber, 3% poles, 33.5% firewood and charcoal, 53% electricity, and 10% residues. There are numerous other feasible uses for woody biomass which have not yet been established at large commercial scale in South Africa. For example, the use of woody biomass for engineered and composite wood products that can be used as building materials for low-cost housing is an area of active research and development. The residues were not valued and assumed to be in mostly in-field wastes from the clearing and control operations, while current market values were used for timber, poles, charcoal and firewood (Wood Southern Africa and Timber Times, 2015).

Eskom is South Africa's power utility that generates electricity with a capacity of 37,745 MW and consumes approximately 122 million tonnes of coal per annum (Eskom, 2015). If suitable wood-based fuels (wood pellets, torrefied wood chips and pellets, charcoal, or bio-syncrude) are supplied to these power stations, they can technically replace coal fuel at 5–10% without major power plant investments or modifications (Baxter, 2005; IEA, 2009). (Eskom, 2010; IEA, 2009). The use of 53% of the available woody biomass from clearing of plant invasions (19 GJ/t lower heating value on oven dry basis) to provide wood fuels for coal co-firing can reduce of Eskom's annual coal demand by 2.9% and add 1132 MW capacity to the electricity supply mix. Similarly, the control of bush encroachment in South Africa to provide wood fuel can replace 0.7% of Eskom's annual coal demand and add 265 MW installed capacity to the electricity supply mix. The value of the electricity produced was determined by the current average electricity generation cost of ZAR0.75/kWh for new coal power plants (Eskom, 2015). The electricity opportunity in Namibia is based on new installed capacity of dedicated wood-fired power stations (De Wet, 2015). A phased installation of capacity was assumed, using 5–50 MW wood power plants and reaching an additional 170 MW installed capacity, and the electricity was valued based on the current average price of N$1.28/kWh. The current charcoal market in Namibia is 100,000 t of charcoal per annum and valued at N$1600/t (Development Consultants for Southern Africa, 2015). With an expanded production from the control of bush encroachment, it was predicted that production of charcoal will increase by 25,000 t per annum until a maximum of 300,000 additional tonnes per annum produced. Similarly, the demand for firewood in Namibia is estimated at 550,000 t per annum (Development Consultants for Southern Africa, 2015). It was assumed that this production would have been maintained, with the additional increase in the supply of firewood from encroacher bush to offset 175,000 of the 550,000 t sourced from non-encroacher bush. The value of firewood was based on current firewood market price N$1700 per tonne; adjusted by 10% to reflect a market preference for 'sustainable and eco-friendly' firewood harvested from bush control programmes instead of unsustainable harvesting from indigenous forests. The value of using biomass of bush encroachment and plant invasion control programmes for electricity and other wood products in South Africa and Namibia is summarised in Table 2.

3.2.4. Carbon emissions

The carbon emission reductions from using wood fuels instead of fossil fuels for electricity production were assessed. Since Eskom's annual carbon emissions from electricity generated by coal power stations are 231.9 million tonnes of carbon dioxide equivalents, (tCO_{2eq}), the replacement of 2.9% of Eskom's annual coal from wood fuels provided by the clearing of woody invasive alien plants can reduce these carbon emissions by 133 million tCO_{2eq} over 25 years (Eskom 2014). Similarly, the control of bush encroachment can replace 0.7% of Eskom's annual coal demand and reduce the emissions of 31 million tCO_{2eq} over the 25 year period. A market value of ZAR120/tCO_{2eq} was used as this is the avoided cost from the proposed Carbon Tax in South Africa (Carbon report 2015). For Namibia, the average greenhouse gas emissions for electricity produced from coal is 0.4898 tCO_{2eq}/MWh. The use of woody biomass instead of coal to produce electricity will reduce carbon emissions by between 0.4638 and 0.4578 tCO_{2eq}/MW h (WSP, 2012). The Namibian market value of N$60/$tCO_{2eq}$ was used as this has been recommended by National Integrated Resource Plan review (von Oertzen, 2015). The value of carbon emission reduction by using the biomass of bush encroachment and plant invasion control programmes for electricity and other wood products in South Africa and Namibia is summarised in Table 2.

3.3. Valuation of ecosystem services from the clearing of by plant invasions and the control bush encroachment

The valuation results for the key provisioning and regulating services described above are summarised in Table 2 and Fig. 3. Separate assessments were carried out for South Africa and Namibia; the valuation from the clearing of invasive alien plants and bush encroachment in South Africa, and the control of Bush encroachment in Namibia. Note that these benefits only refer to key provisioning and regulating ecosystem service benefits, with the additional costs for infrastructure required to deliver these benefits to society not valued. The only direct cost that was assessed in these studies is the clearing of invasive alien plants and the thinning of bush encroachment in the respective countries, based on the costs of current practice.

The estimated value of ecosystem services from restoring bush encroached land in Namibia was US$5.8 billion. In South Africa, estimated value of ecosystem services from the restoration bush encroachment was US$2.1 billion, while the ecosystem services from the restoration plant invasions were valued at US $6.6 billion (US$8.7 billion for both). The largest ecosystem service benefit for South Africa was for value added industries while for Namibia, it was groundwater recharge. The proportional value of these benefits in Namibia: 69.7% water, 8.6% grazing, 5.4% charcoal, 1.6% firewood, and 14.3% electricity; and 0.3% for the avoided carbon emissions by replacing coal with wood fuels for electricity generation. In South Africa, the proportional value of these benefits for control of both bush encroachment and plant invasions are: 33.3% water, 2.1% grazing, 2.2% timber, 1.3% poles, 9.1% firewood and charcoal, 42.8% electricity, and 9.1% for the avoided carbon emissions replacing coal with wood fuels for electricity generation. However, the value of these carbon emissions reduction does not include the greenhouse gas emissions of land-use change from the clearing and thinning of woody invading plants and encroaching bush, nor does it include the carbon emissions from the subsequent land-use practice; such as the expansion of animal husbandry from the additional grazing capacity generated from the. From our estimates, these losses in ecosystem carbon stocks may outweigh the carbon emission reductions from the use of woody biomass to displace coal for electricity production, and therefore there will likely be net cost in terms of carbon emissions.

The value of these key ecosystem services are considerable, but they should also be seen in light with the direct costs to clear invasive plant invasions and control bush encroachment. For Namibia, the total cost for the control of bush encroachment was estimated at US$2.1 billion (De Wet, 2015). In South Africa, the clearing cost vary widely with locality, but an average cost of ZAR9000/ha (condensed or 100% invaded) and 35 person days required to clear 1 ha was used; since these are the typical costs of the government's Working for Water programme (DEA-NRM, 2015, pers commun.). The cost control of bush encroachment were assumed to be 40% lower compared to alien plant invasions, due to flatter topography and the smaller-sized trees in the bush encroached areas. This implies a total cost of US$1.2 billion for alien plant clearing, and US$0.61 billion for control of bush encroachment. However, these costs do not include follow up and maintenance needed over several years to prevent local re-growth and the spread of plant invasions beyond their current range. If five follow-up treatments are needed and each subsequent follow up treatment has a cost-reduction of 37%; then an additional US$0.71 billion will be needed for alien plant invasions and US$0.38 billion for bush encroachment- bringing the total cost to US$1.9 billion for alien plant invasions and US$$1.1 billion for bush encroachment in South Africa.

Nonetheless, in both Namibia and South Africa, these costs are less than benefits of ecosystem services delivered from the clearing of plant invasions and control of bush encroachment (Table 2).

4. Discussion

Ecosystems provide a range of services, many of which are vital to human well-being. The functionality of ecosystems depends on the composition, structure, and function of biodiversity. Biodiversity is a concept that captures the potential supply of ecosystem services from species, habitats and processes; while the ecosystems concept focuses on the benefits to human well-being in terms of provisioning, regulating, supporting/habitat and cultural dimensions (e.g., Millenium Ecosystem Assessment, 2005 and Noss, 1990). However, the link between biodiversity and ecosystem services and ecosystems is complex. There may also be dis-services, there are trade-offs to be made amongst the services, abiotic resources need to be considered, the outcomes depend on the stakeholders and spatial scales, and significant human and capital investments are often required to deliver these ecosystem services (Lele et al. 2013; Innes and Hoen, 2005).

This study valued a few key ecosystem services, which is by no means exhaustive of the range of provisioning, regulating, supporting and cultural ecosystem services that constitute the total economic value of landscape restoration. However, any assessment of ecosystem services represents a subjective selection of the most important ecosystem services to the respective society (ELD, 2015a). The ecosystem services valued in this study were key provisioning and regulating ecosystem service that have use value (Merlo and Croitoru, 2005), and existing well-established markets. The benefits from these ecosystem services can therefore be considered as having tangible value to individuals and certain economic benefits. In addition, since only a select few ecosystem services were valued, the overall ecosystem service benefits are likely to be considerably greater when one considers the full spectrum of use and non-use value (Costanza et al.1997; Turpie, 2004; De Lange and Van Wilgen, 2010). Our results indicate that the management of invasive alien plants and bush encroachment can deliver significant ecosystem services benefits, whose value outweighs the cost of management and control.

The impacts from bush encroachment include of serious socio-economic concern in arid and semi-arid regions, such as southern Africa, where other forms of agriculture are not feasible on account of the low rainfall and water scarcity. From an ecological perspective, bush encroachment may be seen as a natural process involving competition between the tree and grass component of savannah. However, the anthropogenic driving pressures of bush encroachment include the increased grazing from animal husbandry and frequent fires that reduces the grassy layer and enhances bush encroachment (Kraaij and Ward, 2006; Ward, 2005). Similarly, the anthropogenic pressures of increasing human migration and habitat destruction has led to the introduction of invasive alien plants into South Africa and the conversion of species-rich vegetation to single-species stands of trees; such as the Australian wattles (*Acacia* spp.) and gums (*Eucalyptus* spp.). Since many of South Africa's riparian habitats have been transformed and degraded by alien tree species there are ‘few, if any, river systems that have not been extensively invaded’ (Richardson and Van Wilgen, 2004, p. 46) and the impacts on water resources are significant (Le Maitre et al., 2000; Görgens and Van Wilgen, 2004). Our results reiterate the value of these water resources which is particularly relevant for both countries that are semi-arid with limiting water resources and growing water scarcity. These impacts are likely to increase in the future due to climate change that will reduce water availability and increase woody biomass growth from a ‘carbon fertilisation’ effect (Bond and Midgley, 2012). Therefore, the value of the water that can be made available from the restoration of lands impacted by bush encroachment and alien plant invasions is likely to be under estimated in our study. Furthermore, bush encroachment and plant invasions also impact biodiversity, increase fire intensity that leads to soil erosion and land degradation. This has downstream socio-economic impacts and reduces the capacity of the land to support agriculture, livestock and wildlife.

The demand for additional grazing capacity is increasing due population growth, increased per capita income, and the cultural and social preference for a high-meat diet, as well as the decline in land productivity and grazing potential. The estimated value of the additional grazing capacity from the removal and control of either bush encroachment or invasive alien plant species is significant, although its value is less than that of the water or electricity provided. As shown by this study, the use of biomass for electricity can deliver notable carbon emission reductions through the replacement of coal, and biomass co-firing is noted as an important greenhouse gas abatement opportunity (McKinsey and Co. 2010). The carbon emission reductions from using biomass for electricity could be traded as certified emission reductions on the carbon markets (Niemack and Chevallier, 2010) and our results show that they can could increase the revenue from electricity sales by 21%. In addition, various wood products (fence posts, poles) could also reduce net carbon emissions by increasing terrestrial carbon stocks; although this was not assessed due to lack of clear boundaries and data.

However, some precautionary measures will be needed in implementing the restoration programmes to avoid unintended effects and a reduction in the expected benefits. Since woody vegetation is a significant carbon sink, removal of woody biomass will likely decrease the amount of carbon in an ecosystem (Houghton, 2003). Further, if land is used for grazing, the enhanced ecosystem services from the clearing of plant invasions and bush encroachment will be offset by the carbon emissions and water consumption from animal husbandry. Our assessment of carbon emissions considers the carbon emission reductions from woody using biomass from plant invasions and bush encroachment to replace coal for the generation of electricity. However, it does not include land use changes and land management practices. Generally, a change from bush encroachment or woody plant invasions to the natural vegetation of the eco-region will result in a net loss in terrestrial carbon stocks, due to the loss of rapidly growing woody biomass. The loss of carbon stocks will depend on natural vegetation type, but could be 20–70 tC/ha (Wessman et al., 2004; Hudak et al., 2003; Blaser et al., 2014; Carbon Report 2015). In addition, there may also be carbon emissions from the land-use practice that follows the clearing of plant invasions and control of bush encroachment. For example, If cleared land is used for grazing and cattle rearing there will likely be additional 12–16 $kgCO_{2eq}$ per kg live weight of cattle (Garnett, 2009); due to methane from enteric fermentation, and the nitrous oxide from excreted nitrogen and chemical nitrogenous fertilizers used to produce feed (Lesschen et al., 2011; Herrero et al., 2011; O'Mara, 2011; Janzen, 2011; Reay et al., 2012). This illustrates that land use change and land use practice can have significant effects on total ecosystem carbon and could negate the carbon emission reductions of using biomass for electricity. However, there is considerable uncertainty in many of these estimates due to the uncertainty in future land use changes and soil carbon dynamics, the various vegetation types and vegetation cover at a given locality, and the lack of a definitive historical baseline prior to bush encroachment and alien plant invasions. Consequently, there is uncertainty if the expected soil carbon equilibrium state will be reached, when it will be reached, and what the new soil carbon equilibrium state will be. As a result of these uncertainties, the accounting for direct and indirect land-use changes in the carbon accounting mechanisms and carbon markets is currently poorly established. In addition, although the clearing of bush encroachment and alien plant invasions will increase water availability, if land is used for grazing the water availability will be reduced since each livestock (LSU) requires approximately fifty litres per day (NDA, 2010).

There are some notable risks to achieving the ecosystem service benefits from landscape restoration operations. For example, mechanical means of plant control can disrupt the soil and non-encroacher vegetation while chemical means have the potential to poison non-target vegetation and pollute water resources. The benefits from restoring lands impacted by alien plant invasions and bush encroachment will also depend on the subsequent land use and land use practices. There are several other land use options aside from livestock rearing; including game farming, agriculture, forestry and ecotourism, that are influenced by the ecoclimate, local resources. The prevailing land use and land use practices will have various impacts on biodiversity and ecosystem services, which will influence the net benefits of landscape restoration. For example, a decline in the profitability of traditional cattle ranching in several parts of Namibia is causing a change in land use to eco-tourism, game farming and hunting; which often delivers additional benefits in terms of enhancing ecosystem servives (Milton et al. 2003). Therefore, land cleared of plant invasions and bush encroachment will require maintenance and appropriate land management in order to prevent the depletion of natural capital and land degradation.

A variety of timber and non-timber products can be produced from woody biomass of invasive alien plants and bush encroachment, including: timber and lumber; engineered wood; paper and composite wood products; soil improvers, feed and fodder; fine chemicals; and biomass fuels and energy. These products represent opportunities for cost recovery in landscape restoration since they are only available for the time period of the restoration programme- 25 years in this study. The market demand for wood products continues to rise at 2.7% per year (FAO, 2015), and there is a growing interest in engineered and composite wood products as virgin timber and lumber is becoming more expensive. From our assessment of the woody biomass resources, made available from the clearing of invasive alien plants and the control of bush encroachment, only a small portion of biomass (2%) is suited to high market value products (i.e. timber and poles). These wood products are high-value, low volume and contribute relatively little to the total biomass value. In contrast, biomass to electricity makes a major contribution the total biomass value; since it is a low-value, high-volume product that is less constrained by wood quality and can access a larger portion of the biomass resource. However, the opportunities biomass utilisation will need to consider emerging products currently being actively researched and developed; such as the use of wood composites to replace timber and building materials in low cost housing.

In order to derive a thorough understanding of the benefits of restoration, it is also important to take into consideration the related secondary and multiplier effects. The clearing alien plant invasions and encroaching bush is a labour-intensive task, even with the aid of machinery, and therefore creates numerous employment opportunities. Many of these additional employment opportunities can benefit the rural poor; thereby also contributing to sustainable rural livelihoods, economic growth and more equitable development. In addition, several provisioning services have inherent socio-economic multiplier effects. For example, the clearing of plant invasions and bush encroachment can increase the provision of water, wood fuels and electricity, which are both market goods and a means of production that enable a whole range of human and societal functions.

The valuation of ecosystem services is arguably a valuable tool to advocate pro-environmental behaviour and landscape restoration (Costanza et al., 1997, de Groot et al., 2010, 2012). Changing human behaviour and developing a shared knowledge and an understanding of the drivers amongst actors and stakeholders, as well as their and their willingness to be involved will be key determinants of success in implementing landscape restoration. It is therefore important to understand how the benefits from controlling bush encroachment and invasive plant species are distributed among sectors and at the local, regional, national and international level. Due consideration must be taken that the outcomes from land restoration might not benefit the same persons affected by plant invasions and bush encroachment. Furthermore, the benefits from implementing restoration activities will most likely not materialise immediately or unfold in a linear fashion. Working with socio-ecological systems therefore requires long-term planning and strategy that can incorporate the required investments for ensuring the restoration of landscapes. National policies must be supported by applicable tools and options at the local scale (ELD, 2015b), so that there is policy coherence and coordinated action that works towards achieving a prosperous and equitable society living in harmony with natural resources.

5. Conclusions

Bush encroachment and the invasion of alien plant species alter the composition and/or balance of species in natural ecosystems, and are significantly contributors to land degradation and denudation. The impacts of bush encroachment and the alien plant invasions on ecosystems include considerable losses in terms of biodiversity, land productivity and water availability.

In Namibia, the estimated value of ecosystem services from the restoration of bush encroachment was US$5.8 billion. In South Africa, the value of ecosystem services from the restoration of bush encroachment was estimated to be US$2.1 billion, while the value of ecosystem services from the restoration of alien plant invasions was estimated to be US$6.6 billion. For both countries, the most valued ecosystem service benefit assessed was water; which accounted for 33.3% of the total benefits in South Africa and 69.7% in Namibia. The value of these ecosystem services is considerably greater than the direct costs involved in the operations to clear invasive alien plants control bush encroachment. An estimated US$2.1 billion is required to control bush encroachment in Namibia, US$1.9 billion to clear alien plant invasions in South Africa, and S$1.1 billion to control bush encroachment in South Africa.

Although this partial economic analysis of the benefits of ecosystem service from land restoration does not include a range of ecosystem services or the additional infrastructure investments needed to deliver these services to society, it clearly illustrates that the benefits of restoration will far outweigh the clearing costs involved.

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