THE OPPORTUNITY COST OF NOT UTILISING THE WOODY INVASIVE ALIEN PLANT SPECIES IN THE KOUGA, KROM AND BAVIAANS CATCHMENTS IN SOUTH AFRICA

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Abstract

This study estimates the opportunity costs of using woody invasive alien plants (IAPs) for value-added products by estimating the net economic return from the value-added industries in South Africa. By 2008, IAPs were estimated at the national level to cover an area of 1 813 million condensed hectares in South Africa. A market has formed around their use for value-added products (VAP) like charcoal, firewood and timber in the Kouga, Kromme and Bavaians River catchments in the Eastern Cape province of South Africa. The net economic return from these value-added industries was estimated for the purpose of several management scenarios, and was then used to estimate the opportunity costs if they were not used. A system dynamics model was used to value and analyse the Net Present Value of clearing in the study area and to estimate the opportunity cost of the non-use of VAP. The study showed that the inclusion of VAPs in the project would yield higher net present values for clearing. The findings from this study suggest that a co-finance option of the total economic returns from VAP for clearing costs is the best management scenario for reducing the costs of clearing and maximising the net economic returns from clearing. The net economic returns of VAPs by 2030 are estimated at R23 million without the co-finance option and R26 million with the option. The cumulative net income from VAPs with co-financing over the period of valuation is estimated to be R609 million.

Key words: opportunity cost, alien invasive plants, direct use value, eradication through utilisation

JEL: Q24, 25, 42

1 Introduction

Biological invasions are a significant threat to land productivity, biodiversity and the ecosystem goods and services provided for society in general (Nellemann & Corcoran, 2010). In South Africa the National Department of Environmental Affairs: Natural Resource Management (DEA:NRM) is tasked with the management and control of invasive alien plants (IAPs). As early as the 1900s, the potentially unfavourable impact of IAPs on South Africa’s natural fynbos vegetation was acknowledged (Moran, Hoffman & Zimmermann, 2013). Later, (Cowling, 1992), the DEA:NRM programme was commissioned in 1995 to control IAPs (Van Wilgen, Cowling & Burgers, 1996; Blignaut, Marais & Turpie, 2007; Blignaut, Mander, Schulze, Horan, Dickens, Pringle, Mavundla, Mahlangu, Wilson, McKenzie & McKean, 2010).

Research on resource economics has been instrumental in providing motivation for the expensive DEA:NRM programme, and several South African studies have used a cost-benefit analysis of clearing IAPs to inform decision-making (e.g. Van Wilgen, Cowling & Burgers, 1996; Higgins, Richardson & Cowling, 1996; Hosking & Du Preez, 1999; Hosking & Du Preez, 2004; Turpie & Heydenrych, 2000; De Wit, Crookes & Van Wilgen., 2001; Wise, Van Wilgen & Le Maitre, 2012). This study is intended to contribute to the growing number of studies by investigating the potential benefit of private-sector investment in the DEA:NRM programme.
Potential economic gains from IAPs present an opportunity for government to source co-funding from the private sector for the control and management of IAPs, and, in the process, support rural livelihoods through the sale of products derived from IAPs (Van Wilgen & Richardson, 2012; Shackleton, Le Maitre, Pasiecznik & Richardson, 2014). However, there are challenges, especially when it comes to the extraction of IAPs. Mugido, Blignaut, Joubert, De Wet, Knipe, Joubert, Cobbing, Jansen, Le Maitre & Van Der Vyfer (2014) suggest on-site processing as a possible alternative to addressing the issue with transportation. It is also clear that conflict-of-interest species, such as black wattle, pine trees and *Prosopis*, require innovative methods of management. Currie, Milton, & Steenkamp (2009) conducted a cost benefit analysis (CBA) of clearing *Pinus* species and restoring fynbos in the Assegaaibos mountain catchment area in the Western Cape province of South Africa. They found that the NPV of clearing *Pinus* species and restoring fynbos was always negative, regardless of the discount rate used. However, if the economic value of the IAPs is used to co-finance the operations, this could result in a feasible option. Thus, this study sought to determine the costs and benefits of early restoration in the Kouga-Krom catchment area in the Eastern Cape province of South Africa. As some of the species that are being cleared by the DEA:NRM are of commercial value, this study estimated the opportunity costs of not using IAPs for value-added industries. Further, the study also estimated the Unit Reference Value (URV) for clearing IAPs in the Kouga-Krom study area.

2 Site description

The study area (referred to as Kouga-Krom) falls within the Kromme, Kouga and Bavaians river catchments in the Eastern Cape Province, near Jeffrey’s Bay. It spans a total of 5 234.24 km², with a mean annual rainfall ranging between 500–2 000 mm per annum (SAWS, 2015). It consists of two biome types, fynbos (80 per cent) and Albany thicket (20 per cent) (Mander, Blignaut, Van Niekerk, Cowling, Horan, Knoesen, Mills, Powell & Schulze, 2010), both of which are biodiversity hotspots and areas of high endemism (Global Biodiversity Outlook, 2010; Hoare, Mucina, Rutherford, Vlok, Euston-Brown, Palmer, Powrie, Lechmere-Oertel, Proches, Dold & Ward, 2006; Myers, 1990) because of the geological features of the area. The fynbos biome is one of the most invaded biomes in South Africa (Richardson, MacDonald, Hoffman & Henderson, 1997; Kotzé, Beukes, Van Den Berg & Newby, 2010).

The study area comprises 14 sub-quaternary catchments, L81A-C, L82A-J & L90A-C within the Fish to Tsitsikamma river catchment. The majority of the land is under private land tenure (Mander, Blignaut, Van Niekerk, Cowling, Horan, Knoesen, Mills, Powell & Schulze, 2010), with intensive deciduous fruit, lucerne and citrus production (Jansen, 2008). Protected areas are limited to the upper regions of the study area in the Bavaians catchment and it is recognised internationally as a world heritage site (Jansen, 2008). The study area is largely rural, containing only small communities, while the population density is generally low, with 20–40 people/km² and unemployment in the area is high, ranging from 30–40 per cent (StatsSA, 2011).

The study area is under additional pressure from extensive farming and other agricultural activities in the area (Mander, Blignaut, van Niekerk, Cowling, Horan, Knoesen, Mills, Powell & Schulze, 2010; Jansen, 2008). IAPs are an increasing problem, particularly in the lower regions, with *Acacia baileyana*, *A. dealbata* & *A. mearnsii* (hereafter referred to as Wattle spp) being one of the greatest threats in the area (Mander, Blignaut, van Niekerk, Cowling, Horan, Knoesen, Mills, Powell & Schulze, 2010). Table 1 outlines the current extent of invasion in the study area. These pressures increase the strain on the availability of water for the catchment.

3 Methods and material

3.1 Data collected

Primary data was sourced during a series of site visits and group discussions, with experts, as well as implementing agents for the DEA:NRM programme. The data gathered from experts and
implementing agents was supplemented with data from the literature on the indicators required for an economic analysis. The condensed values for the IAPs and related information were extracted from the (2010) database for Kotzé, Beukes, Van Den Burg & Newby (see Table 1). This study focuses exclusively on the five dominant species found in the areas noted by Kotzé, Beukes, Van Den Berg & Newby (2010).

### Table 1
Current extent of invasion in the study area and spread rates of the respective species

<table>
<thead>
<tr>
<th>Species</th>
<th>Extent of invasion (condensed ha)</th>
<th>Spread rates (% per year)</th>
<th>Species density (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattle spp</td>
<td>8 584.38</td>
<td>10.00</td>
<td>4.18</td>
</tr>
<tr>
<td>Hakea spp</td>
<td>3 761.88</td>
<td>8.80</td>
<td>4.72</td>
</tr>
<tr>
<td>Other</td>
<td>2 483.08</td>
<td>-</td>
<td>0.14</td>
</tr>
<tr>
<td>Pinus spp</td>
<td>2 055.51</td>
<td>8.15</td>
<td>0.55</td>
</tr>
<tr>
<td>Acacia saligna</td>
<td>679.77</td>
<td>10.00</td>
<td>0.31</td>
</tr>
<tr>
<td>Atriplex donax</td>
<td>254.06</td>
<td>10.00</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Sources: Adapted from Kotzé et al. (2010) and Van Wilgen & Le Maitre (2013)

#### 3.1.1 Value added products

Only the main benefits deriving from Wattle spp. and *Acacia saligna* and *Pinus* species were considered in this study, as the benefits of the other IAP species are not considered economically significant (CABI, 2016). Wattle spp., for example, are Australian *Acacia* species and comprise a combination of *Acacia baileyana*, *A. dealbata* and *A. mearnsii*. These were intentionally introduced into South Africa for the ecological services they provide, such as serving as wind breaks and providing fuel (De Wit, Crookes, Van Wilgen, 2001; Nyoka, 2003). Wattle spp. have become one of South Africa’s most widespread IAPs (Nyoka, 2003; Versfeld, Le Maitre & Chapman, 1998; Dye & Jarmain, 2004), and thus became the most targeted IAPs, with almost a third of all the clearing costs attributed to the control of Wattle spp. (Wise, Van Wilgen, & Le Maitre, 2012). The investment in controlling IAPs in the Kouga-Krom catchment for the period 2008-2014 is provided in Table 2.

### Table 2
Historical nominal and real values for clearing data from DEA: NRM: Kouga-Krom

<table>
<thead>
<tr>
<th>Year</th>
<th>Actual clearing costs (R)</th>
<th>Clearing costs in constant 2014 prices (R)</th>
<th>Area cleared (condensed ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>2 604 939.68</td>
<td>3 695 156.72</td>
<td>1 994.21</td>
</tr>
<tr>
<td>2009</td>
<td>3 446 823.56</td>
<td>4 612 627.45</td>
<td>793.05</td>
</tr>
<tr>
<td>2010</td>
<td>6 590 916.35</td>
<td>8 320 880.04</td>
<td>2 740.38</td>
</tr>
<tr>
<td>2011</td>
<td>8 669 108.25</td>
<td>10 325 046.63</td>
<td>3 339.05</td>
</tr>
<tr>
<td>2012</td>
<td>7 386 950.53</td>
<td>8 299 977.62</td>
<td>3 793.70</td>
</tr>
<tr>
<td>2013</td>
<td>5 998 088.38</td>
<td>6 357 973.68</td>
<td>481.42</td>
</tr>
<tr>
<td>2014</td>
<td>5 700 437.89</td>
<td>5 700 437.89</td>
<td>315.07</td>
</tr>
</tbody>
</table>

Source: Adapted from DEA: NRM (2015)

While it is important to control IAPs with their detrimental effects on a range of ecosystem goods and services, such as water flows, they can be used to generate value through a range of value-added products (VAP), which are listed in Table 3.
Table 3
Benefits associated with the five dominant species of the study area

<table>
<thead>
<tr>
<th>Benefit</th>
<th>Description</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tannins extracted from bark</td>
<td>Tanning agents used in the production of soft leather</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acacia saligna</td>
</tr>
<tr>
<td>Timber</td>
<td>Building materials and mining timber</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pine spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acacia saligna</td>
</tr>
<tr>
<td>Pulp</td>
<td>Mainly exported, for the production of paper and other products</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pine spp.</td>
</tr>
<tr>
<td>Wood chips</td>
<td>Used in the production of paper</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pine spp.</td>
</tr>
<tr>
<td>Charcoal</td>
<td>Fuel used in barbecues</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pine spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acacia saligna</td>
</tr>
<tr>
<td>Firewood</td>
<td>An important fuel source for rural communities</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acacia saligna</td>
</tr>
<tr>
<td>Building materials</td>
<td>Used to support housing structures in rural areas</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td>Carbon sequestration</td>
<td>Standing plantations and invasions store carbon as a counter to carbon build-up in the atmosphere, mainly from fossil fuel burning, which can potentially be traded</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pinus spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acacia saligna</td>
</tr>
<tr>
<td>Nitrogen fixation</td>
<td>Addition of nitrogen through fixation by roots could be regarded as either a benefit or a cost in some areas</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acacia saligna</td>
</tr>
<tr>
<td>Medicinal products</td>
<td>Possible use as styptics or astringents</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td>Combating erosion</td>
<td>Decrease erosion in severely degraded sites away from river courses</td>
<td>Wattle spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pinus spp.</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>Non-direct use, but appreciation of resource</td>
<td>Pinus spp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hakea spp.</td>
</tr>
</tbody>
</table>

Source: Adapted from De Wit et al. (2001) and CABI (2016)

3.2 Development of an economic model

The economic model used in this study is a system dynamics model based on the work of Forrester (1961), and will be described below. Vensin® software was used for the conceptualisation and development of the economic model to estimate the opportunity costs of not using IAPs for commercial benefit (Ventana Systems, 2003).

3.2.1 Model description

The model investigated the benefits and cost of early restoration in relation to waiting until an area becomes heavily invaded. The model further investigates the potential benefits of value-added industries to the DEA:NRM programme through recommending a policy variable co-financing to reduce the costs of clearing. The model was run for 22 years (2008–2030) and consisted of six sub-models, which were land use, clearing cost, value-added products, water consumption, carbon sequestration and economic factors.

The sub-model for land use focused on the extent of alien invasion and clearance at the study area (see Figure 1). The parameters informing this sub-model are listed in Table 1. The stock variables are areas invaded by Hakea spp., Wattle spp., Pinus spp., Atriplex donax, Acacia saligna and other species. The ‘other species’ represent the less dominant IAPs found at the study site. Each stock variable in the land-use sub-model depicts the extent of invasion, which is increased by regrowth and reduced by clearance. The IAP regrowth is increased by the spread rate and the area invaded. The IAP clearance is a function of person days which, in turn, are a function of the budget. Regression models were run in the Vensim® modelling software to estimate the functions.
The value-added products sub-model in this study was concerned with estimating the net economic returns from VAPs. The biomass values were allocated to a selection of VAPs (see Table 4). The quantities were corrected for losses and then multiplied by the corresponding prices to yield the total revenue from each. The summation of the total revenue multiplied by the profit margin ratio yielded the net income from VAPs. The parameters informing this sub-model are listed in Table 4. Values that inform more than one sub-model are not repeated. To establish confidence in the developed model several validity test were applied in Vensim®. A short description of the validity test applied in this study is provided in the Appendix.

**Figure 1**

Land use sub-model for the Kouga-Krom study area
carbon is a product of the species biomass, clearance, percent carbon (i.e. percent oven dry carbon during the photosynthesis process), and, the water value that is lost owing to clearing IAPs at the study site. Table 6 shows the parameters set for this sub-model. IAPs use carbon during the photosynthesis process and, in turn, reduce greenhouse gases in the atmosphere. For this reason, the carbon sequestration potential is lost when IAPs are cleared. The sequestered carbon is a product of the species biomass, clearance, percent carbon (i.e. percent oven dry biomass) and the C:CO₂ ratio. The model equations are found in Appendix A.
Table 6
Parameters informing the carbon sequestration sub-model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Units</th>
<th>Data Source</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon sequestration per ha Atriplex donax</td>
<td>74.25</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>Carbon sequestration per ha Pinus spp.</td>
<td>135.81</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>Carbon sequestration per ha Hakea spp.</td>
<td>74.25</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>Carbon sequestration per ha Wattle spp.</td>
<td>59.02</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>Carbon sequestration per ha Acacia saligna</td>
<td>29.87</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>Carbon sequestration per ha other species</td>
<td>74.25</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>Carbon Sequestration Acacia saligna</td>
<td>29.87</td>
<td>ton/ha</td>
<td>Mugido et al. (2014)</td>
<td>2014</td>
</tr>
<tr>
<td>A factor correcting for net carbon</td>
<td>0.05</td>
<td>dml</td>
<td>Assumption</td>
<td>2015</td>
</tr>
<tr>
<td>Unit price of carbon</td>
<td>120</td>
<td>R/ton</td>
<td>National Treasury (2013)</td>
<td>2014</td>
</tr>
</tbody>
</table>

While there are several potential land uses after clearing the IAPs, we focus here on grazing. For this reason, the grazing value sub-model (see Figure 2) models the net income that could be derived from livestock (mainly sheep) production at the study site once the IAPs have been cleared. This sub-model therefore models only small stock units (SSU). The hectares grazed by SSU are given by the area cleared and corrected, as the entire area could not be used for potential grazing (i.e. the factor “% grazing under SSU”). The hectares grazed by SSU multiplied by the SSU weight production (ha/yr) yields the weight production by SSU. The SSU weight production is a product of the LSU weight production and the LSU to SSU conversion factor of 6.67. The weight production together with the unit price of SSU yields the total revenue from SSU. This is then multiplied with the profit-margin ratio to determine the net income from grazing SSU. A list of the parameters that informed this model is given in Table 7.

Figure 2
Grazing value sub-model
Table 7
Grazing value sub-model parameters

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Units</th>
<th>Data source</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSU weight production commercial</td>
<td>16</td>
<td>kg/ha/yr</td>
<td>De Wit et al. (2015)</td>
</tr>
<tr>
<td>SSU to LSU</td>
<td>6.67</td>
<td>dml</td>
<td>Herling et al. (2009)</td>
</tr>
<tr>
<td>Unit price SSU</td>
<td>30</td>
<td>R/kg</td>
<td>De Wit et al. (2015)</td>
</tr>
<tr>
<td>% grazing</td>
<td>0.5</td>
<td>dml</td>
<td>Assumption</td>
</tr>
<tr>
<td>Commercial grazing</td>
<td>1</td>
<td>dml</td>
<td>Assumption</td>
</tr>
</tbody>
</table>

The clearing cost sub-model demonstrates the total cost of clearing the IAPs for the study site. The unit clearing cost is calculated by dividing the budget by the annual IAP clearance. The budget denotes either the funds that were invested by DEA to clear IAPs at the study site between 2008 and 2015 and/or an exploration of various budget-related clearing interventions aimed at reducing IAPs between 2015 and 2030. The product of the unit clearing cost and the annual IAP clearance yields the total clearing cost.

The economic sub-model estimates both the net income from clearing IAPs at the study site and the URV. The applied discount rate for this study is 6 per cent, based on a suite of rates used by government. The net income from clearing IAPs is the sum of i) the net income from VAPs, ii) the value of the water saved, iii) net income from grazing, and less i) the net carbon value lost and ii) the cost of clearing the IAPs. The calculated cumulative PV clearing cost and cumulative PV water volume were used to determine the URV (Unit Reference Value). The URV, which represents the cost of water per cubic metre over the lifetime of a water infrastructure project and is estimated for comparability with other study areas regarding the cost-effectiveness of various clearing operations is therefore calculated as:

\[ URV = \frac{PV \text{ of costs}}{PV \text{ of quantity of water incrementally assured}} \]

The model validation is performed to test and establish confidence in the model (Forrester & Senge, 1980). Appendix B shows the model validation tests and the outcomes of each validity test.

The study model assumes that the private producers would be willing to co-finance the expense of clearing. Other assumptions in the data in the model include the proportional contribution of each VAP to the net value of value-added industries. It was beyond the scope of this study to quantify the actual proportions of each VAP in the net value of value-added industries. The model assumes that all the grazing value gained in the area is commercial when it comes to the land tenure of the study area, because an insignificant area is under communal land tenure. The model also assumes that only 50 per cent of the area gained from clearing would be suitable for grazing, as not all the cleared area goes to grazing. The final assumption made in the model is the carbon correction factor. This factor (0.05) is applied to cater for the fact that not all the carbon is lost in clearing, as there will be regrowth of some vegetation once the trees have been cleared from the system.

### 3.2.2 Model scenarios

Three scenarios were develop to assess the value of the management options available to DEA:NRM. The Scenarios are described in Table 8 below.

Table 8
Model scenarios used in this study

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i)</td>
<td>Do nothing Clearing intervention for 2008-2014, then no clearing until 2030</td>
</tr>
<tr>
<td>(ii)</td>
<td>DEAK Clearing according to current DEA budget and clearance rate</td>
</tr>
<tr>
<td>(iii)</td>
<td>DEA K+ Clearing according to current DEA budget plus 20% co-finance by private sector</td>
</tr>
</tbody>
</table>
4 Results and findings

4.1 The ‘Do nothing’ option

The area cleared for the three management scenarios is shown in Figure 3(a). Following 2014 in the ‘Do nothing’ option, no area is cleared. Hence, the costs of clearing shown in Figure 3(b) are zero. Figure 3(c) shows the URV as estimated in this study. Because no additional water is generated in this option, the URV is not considered. Once clearing stops the value of carbon lost to clearing becomes zero, as can be seen in Figure 3 (d).

Figure 3
Vensim® system dynamics output (a) is the area cleared in ha/year, (b) shows the cost of clearing in R/year, (c) is the URV in R/m$^3$, and (d) is the value of carbon lost to clearing.

As there are no clearing operations in this management scenario, no water is saved, as shown in Figure 4(a). The water is essentially lost to invasion. Infestation takes up the grazing areas. Figure 4(b) shows that no grazing value is gained in this option. The total net economic returns from the VAPs is estimated at zero as shown in Figure 4 (c), as in this study we are concerned only with the
DEA:NRM cleared biomass. The overall cumulative NPV for this option is R65 million as shown in Figure 4 (d).

4.2 Business as usual option (DEAK)

To clear a total area of 44 400Ha by 2030 a budget of R139 million is required for the business as usual option. The areas cleared and the budget used for each year is shown in Figure 3(a) and (b) respectively. The estimated URV value for this option is shown in Figure 3(c), and is very similar to the DEAK+ option. The estimated average URV value is R1.83/m³ over the duration of the study period. The URV shows an increasing over-time trend. The carbon value lost to clearing in this management option is lower than that in DEAK+ (Figure 3(d)).

The benefits of clearing are highlighted in Figure 4. The model finding estimates the net value of water saved at R63 million per annum for this management scenario. The trend in the value of water saved is shown in Figure 4(a). Another benefit of clearing is the grazing area made available following the clearing. The economic returns from grazing following the clearing operations is shown in Figure 4(b) and is estimated at R25 000 per annum in the DEAK scenario. This benefit is lost in the do nothing option. The model output for the VAP are shown in Figure 4(c), the returns are estimated at R23 million per annum and this amount is entirely for private benefit. This management option yields a positive cumulative NPV (Figure 4 (d), because the benefits in the Figure 4 outweigh the cost outlined in Figure 3(a & c).

4.3 DEA Co-financed Option (DEAK+)

The co-financed option seeks to increase the social benefits of clearing by implementing a 20 per cent co-financing from private beneficiaries by means of a policy variable. This management option yields the highest area cleared using the same DEA:NRM budget, with private co-finance. This is shown in Figure 3(a) where about 51 000 Ha over the duration of the simulation. Figure 3(b) shows the costs of clearing to be R6.8 million per annum (2015 to 2030 and R157 million over the period 2008-2030. This is owing to the increased budget from the co-finance option that is funding the operational costs of clearing. The clearing costs are higher than the business as usual option, owing to the 20 per cent co-finance. The URV value for this option is estimated at R1,81/m³ as shown in Figure 3(c). This value is similar to that of the Business as usual option. The carbon value lost, which is one of the costs of clearing, is illustrated in Figure 3(d).

The value of the water saved was estimated for the co-financed option, and the outputs are illustrated in Figure 4(a). The value of the water saved is estimated at R7.2 million per annum. The grazing value gained through clearing is illustrated by Figure 4(b). The co-financed option has the highest economic returns from grazing gained. Figure 4(c), which illustrates the total economic returns from value-added industries shows that, through the private-public partnership, the net returns are higher than they would be without the co-finance option. This is evident through the value of R26 million per annum for the DEAK+ option compared to the R23 million of DEAK. This option yields a positive cumulative NPV, as illustrated in Figure 4 (d). The NPV of R189 million for DEAK+ is slightly higher than that of R171 million from the business-as-usual scenario.
5 Discussion

The results of this study showed that the current management strategy employed by DEA: NRM (business-as-usual) is not the most economical option. This is mainly owing to the lower clearance rate and reduced benefits of this management option in comparison with other scenarios such as co-financed (DEAK+). NPV of the co-financed scenario (i.e. DEAK+), which explores the feasibility of a public-private partnership through the introduction of a 20 per cent of returns contribution to the costs of the clearing policy variable, suggests that this management option is the best of the three scenarios. By not using the VAPs, as illustrated in the do nothing scenario, the DEA: NRM is running at a negative NPV throughout the duration of the project’s lifetime. A positive NPV outcome is seen from the production of the VAP (DEAK scenario). However, the
income from the VAP is not invested in the costs of clearing. The results of the study also suggest that investing back into clearing cost increases both the clearance rate and the biomass production of VAP, thus increasing the net economic returns from VAPs.

With the inclusion of VAPs, the DEA:NRM could increase the clearing operations and decrease the public cost of clearing. For all the management options, the URVs are greater than 1, which shows that the Present Value (PV) of the project costs is higher than the PV of the project benefits. The URV value is, however, concerned only with the PV of water, but not the other benefits estimated in this study. The URV in South Africa is an important tool, especially in water production. For instance, the South African National Department of Water Affairs uses the URV to determine the cost-effectiveness of dam construction. Erasmus, Denys, Scherman & Van der Berg (2013) note that the URV for raising the Dam wall of Kouga was estimated at R3.09/m³, which is almost twice the URV estimated for water generation through clearing. This suggest that clearing of invasive alien plants is a cost-effective option in protecting the value of the infrastructure as the opportunity cost of not clearing (R3.09/m³) is higher than the cost of clearing (R1,81/m³).

The DEAK+ scenario yields the highest water value saved, and the VAPs substantially increases the NPV of clearing IAPs, the water value saved, the area cleared and the grazing value gained. This makes it the best management option for achieving the most benefits from clearing. Although, Stubbings (1977) found that most private producers are resistant to the notion of co-financing or paying for clearing IAPs, this option may still be an achievable request. The benefits of early restoration are clearly seen throughout all the sub-models.

A major cost quantified in this study is the loss of carbon stock when clearing the IAPs. Essentially, with greater clearance, more carbon stock is lost. Carbon is valued at R120/ton by the National Treasury. This value is probably an over-estimation because it does not take into account the regrowth of indigenous vegetation. A better estimate of the carbon gains and losses requires a comprehensive study. The ‘do nothing’ option yields only the carbon stock benefits, but at the expense of the other benefits, which is why its cumulative NPV is negative.

6 Conclusion and recommendations

The main findings of this study suggest that the DEA:NRM could significantly reduce the cost of clearing through partnering with value-added industries in the use of IAPs through a co-finance of 20 per cent of the total revenue. This would also increase the rate of clearing of IAPs while reducing the costs. Both the amount of water saved and the increase in grazing value are benefits that would directly affect the surrounding communities. This study has shown that in projects in which the IAPs are of commercial benefit, there is potential for the DEA:NRM to partner with the industries in order to reduce the costs, and to increase the benefits of early restoration. The total contribution per annum is estimated at R26 million, which is shown to increase the efficiency of the clearing operations. The opportunity costs of not using the IAPs VAPs are high, and the use of IAPs could significantly improve clearing operations and reduce the overall costs of clearing.

Endnote

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## Appendix A: Model formulas

<table>
<thead>
<tr>
<th>Description</th>
<th>Formula/value</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia saligna clearance</td>
<td>(Effect of PD on ha cleared-5612)*Proportion of Acacia saligna</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Acacia saligna clearance</td>
<td>(Effect of PD on ha cleared-5612)*Proportion of Acacia saligna</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Acacia saligna regrowth</td>
<td>Area Acacia saligna*Spread rate Acacia saligna</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Aliens water value saved</td>
<td>Unit value of water*Aliens water consumption</td>
<td>R/yr</td>
</tr>
<tr>
<td>Annual alien clearance</td>
<td>Atriplex donax clearance+Acacia saligna clearance+Hakea species clearance+Pinus species clearance+Other species clearance+Wattle species clearance</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Area Acacia saligna</td>
<td>Acacia saligna regrowth-Acacia saligna clearance</td>
<td>ha</td>
</tr>
<tr>
<td>Area Atriplex donax</td>
<td>Atriplex donax regrowth-Atriplex donax clearance</td>
<td>ha</td>
</tr>
<tr>
<td>Area Hakea species</td>
<td>Hakea species regrowth-Hakea species clearance</td>
<td>ha</td>
</tr>
<tr>
<td>Area livestock production</td>
<td>Annual alien clearance</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Area other species</td>
<td>Other species regrowth-Other species clearance</td>
<td>ha</td>
</tr>
<tr>
<td>Area Pinus species</td>
<td>Pinus species regrowth-Pinus species clearance</td>
<td>ha</td>
</tr>
<tr>
<td>Area Wattle spp</td>
<td>Wattle spp regrowth-Wattle species clearance</td>
<td>ha</td>
</tr>
<tr>
<td>Atriplex donax clearance</td>
<td>(Effect of PD on ha cleared-5612)*Proportion Atriplex donax</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Atriplex donax regrowth</td>
<td>Area Atriplex donax*Spread rate Atriplex donax</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Briquette</td>
<td>(Utilizable biomass wattle spp<em>Proportion of Wattle species to Briquette</em>Biomass conversion ratio into Briquette<em>Losses)+(Utilizable biomass acacia saligna</em>Proportion of Acacia saligna to Briquette<em>Biomass conversion ratio into Briquette</em>Losses)</td>
<td>ton/yr</td>
</tr>
<tr>
<td>Budget (DEAK+)</td>
<td>Co-finance proportion**Budget (DEAK)(Time)</td>
<td>R</td>
</tr>
<tr>
<td>Cumulative invaded area</td>
<td>Area Atriplex donax+Area Acacia saligna+Area Hakea species+Area other species+Area Wattle spp</td>
<td>ha</td>
</tr>
<tr>
<td>Cumulative NPV Krom</td>
<td>NPV rate</td>
<td>R</td>
</tr>
<tr>
<td>Cumulative PV clearing cost</td>
<td>PV clearing cost rate</td>
<td>R</td>
</tr>
<tr>
<td>Cumulative PV water volume</td>
<td>PV water volume rate</td>
<td>m3</td>
</tr>
<tr>
<td>Effect of budget on person days</td>
<td>Elasticity of person days to budget*LN(&quot;Budget (DEAK+)&quot;)</td>
<td>PD/yr</td>
</tr>
<tr>
<td>Effect of PD on ha cleared</td>
<td>Elasticity of ha cleared to person days*LN(Person days)</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Firewood</td>
<td>(Utilizable biomass wattle spp<em>Biomass conversion ratio into firewood</em>Proportion of Wattle species to firewood<em>Losses)+(Utilizable biomass acacia saligna</em>Biomass conversion ratio into firewood<em>Proportion of Acacia saligna to firewood</em>Losses)</td>
<td>ton/yr</td>
</tr>
<tr>
<td>Grand initial alien area</td>
<td>Initial area Atriplex donax+Initial area Acacia saligna+Initial area Hakea species+Initial area other species+Initial area Wattle species</td>
<td>ha</td>
</tr>
<tr>
<td>Ha grazed: SSU</td>
<td>Area livestock production*&quot;% grazing under SSU&quot;</td>
<td>Ha grazed: SSU</td>
</tr>
<tr>
<td>Hakea species regrowth</td>
<td>Area Hakea species*Spread rate Hakea species</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Aliens water consumption</td>
<td>Water use hakea spp+Water use pinus species+Water use wattle spp+Water use other species+Water use atriplex donax+Water use acacia saligna</td>
<td>m3/yr</td>
</tr>
<tr>
<td>Hakea species clearance</td>
<td>(Effect of PD on ha cleared-5612)*Proportion of Hakea species</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Net carbon stock removed</td>
<td>(Sequestrated carbon Acacia saligna+Sequestrated carbon Atriplex donax clearance+Sequestrated carbon Hakea species+Sequestrated carbon other species+Sequestrated carbon Pinus species+Sequestrated carbon wattle spp)*A factor correcting for net carbon</td>
<td>ton/yr</td>
</tr>
<tr>
<td>Net carbon value lost</td>
<td>Unit price of carbon*Net carbon stock removed</td>
<td>R/yr</td>
</tr>
<tr>
<td>Net income from clearing aliens in Kouga-Krom</td>
<td>(Net income VAPS+Aliens water value saved+&quot;Net income grazing: SSU&quot;)-Net carbon value lost-Total clearing cost</td>
<td>R/yr</td>
</tr>
<tr>
<td>Net income grazing: SSU</td>
<td>Total revenue SSU*Profit margin ratio</td>
<td>R/yr</td>
</tr>
<tr>
<td>Area cleared</td>
<td>Effect of PD on ha cleared-5612</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Charcoal</td>
<td>(Utilizable biomass wattle spp<em>Proportion of Wattle species to charcoal</em>Biomass conversion ratio into charcoal<em>Losses)+(Utilizable biomass acacia saligna</em>Proportion of Acacia saligna to charcoal*Biomass conversion</td>
<td>ton/yr</td>
</tr>
</tbody>
</table>
Net income VAPs

\[
\text{Net income} = VAPs = (\text{Total revenue Briquette} + \text{Total revenue charcoal} + \text{Total revenue firewood} + \text{Total revenue pulp} + \text{Total revenue timber}) \times \text{Profit margin ratio} \quad \text{R/yr}
\]

NPV Krouga-Krom

\[
\text{NPV} = \frac{\text{Net income from clearing aliens in Krouga-Krom}}{\text{Present value factor}} \quad \text{R/yr}
\]

NPV rate

\[
\text{NPV rate} = \frac{\text{NPV Krouga-Krom}}{\text{NPV Krom}} \quad \text{R/yr}
\]

Other species clearance

\[
\text{Other species clearance} = \left(\frac{\text{Effect of PD on ha cleared}}{5612}\right) \times \text{Proportion of other species} \quad \text{ha/yr}
\]

Other species regrowth

\[
\text{Other species regrowth} = \text{Area other species} \times \text{Spread rate others species} \quad \text{ha/yr}
\]

Person days

\[
\text{Person days} = \text{Effect of budget on person days} \times 432746 \quad \text{PD/yr}
\]

Pinus species clearance

\[
\text{Pinus species clearance} = \left(\frac{\text{Effect of PD on ha cleared}}{5612}\right) \times \text{Proportion of Pinus species} \quad \text{ha/yr}
\]

Pinus species regrowth

\[
\text{Pinus species regrowth} = \text{Area Pinus species} \times \text{Spread rate Pinus species} \quad \text{ha/yr}
\]

Present value factor

\[
\text{Present value factor} = \left(\left(\frac{\text{Conversion factor}}{\text{Discount rate}}\right) \times \text{Year of cost} \times \text{Time}\right) \quad \text{Dmnl}
\]

Proportion Atriplex donax

\[
\text{Proportion Atriplex donax} = \frac{\text{Initial area Atriplex donax}}{\text{Grand initial alien area}} \quad \text{Dmnl}
\]

Proportion of Acacia saligna

\[
\text{Proportion of Acacia saligna} = \frac{\text{Initial area Acacia saligna}}{\text{Grand initial alien area}} \quad \text{Dmnl}
\]

Proportion of Hakea species

\[
\text{Proportion of Hakea species} = \frac{\text{Initial area Hakea species}}{\text{Grand initial alien area}} \quad \text{Dmnl}
\]

Proportion of other species

\[
\text{Proportion of other species} = \frac{\text{Initial area other species}}{\text{Grand initial alien area}} \quad \text{Dmnl}
\]

Proportion of Pinus species

\[
\text{Proportion of Pinus species} = \frac{\text{Initial area Pinus species}}{\text{Grand initial alien area}} \quad \text{Dmnl}
\]

Pulp

\[
\text{Pulp} = \text{Utilizable biomass Pinus species} \times \text{Proportion of Pinus species to pulp} \times \text{Biomass conversion ratio into pulp} \times \text{Losses} \quad \text{ton/yr}
\]

PV clearing cost

\[
\text{PV clearing cost} = \text{Total clearing cost} \div \text{Present value factor} \quad \text{R/yr}
\]

PV clearing cost rate

\[
\text{PV clearing cost rate} = \text{PV clearing cost} \quad \text{R/yr}
\]

PV water volume

\[
\text{PV water volume} = \text{Aliens water consumption} \div \text{Present value factor} \quad \text{m3/yr}
\]

PV water volume rate

\[
\text{PV water volume rate} = \frac{\text{PV water volume}}{\text{yr}} \quad \text{m3/yr}
\]

Sequestrated carbon Acacia saligna

\[
\text{Sequestrated carbon Acacia saligna} = \text{Acacia saligna biomass} \div \text{Acacia saligna clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

Sequestrated carbon Atriplex donax clearance

\[
\text{Sequestrated carbon Atriplex donax clearance} = \text{Atriplex donax clearance biomass} \div \text{Atriplex donax clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

Sequestrated carbon Atriplex donax clearance

\[
\text{Sequestrated carbon Atriplex donax clearance} = \text{Atriplex donax clearance biomass} \div \text{Atriplex donax clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

Sequestrated carbon Hakea species

\[
\text{Sequestrated carbon Hakea species} = \text{Hakea species biomass} \div \text{Hakea species clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

Sequestrated carbon other species

\[
\text{Sequestrated carbon other species} = \text{Other species biomass} \div \text{Other species clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

Sequestrated carbon Pinus species

\[
\text{Sequestrated carbon Pinus species} = \text{Pinus species biomass} \div \text{Pinus species clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

Sequestrated carbon wattle spp

\[
\text{Sequestrated carbon wattle spp} = \text{Wattle species biomass} \div \text{Wattle species clearance} \times \text{Percent carbon} \times \text{C:CO2 ratio} \quad \text{ton/yr}
\]

"SSU weight production: Commercial"

\[
\text{"SSU weight production: Commercial"} = \text{Utilizable biomass Pinus species} \div \text{Proportion of Pinus species to timber} \times \text{Biomass conversion ratio into timber} \times \text{Losses} \quad \text{kg/(ha*year)}
\]

Timber

\[
\text{Timber} = \text{Utilizable biomass Pinus species} \div \text{Proportion of Pinus species to timber} \times \text{Biomass conversion ratio into timber} \times \text{Losses} \quad \text{ton/yr}
\]

Total clearing cost

\[
\text{Total clearing cost} = \text{Unit clearing cost} \times \text{Annual alien clearance} \quad \text{R/yr}
\]

Total revenue Briquette

\[
\text{Total revenue Briquette} = \text{Briquette price} \quad \text{R/yr}
\]

Total revenue charcoal

\[
\text{Total revenue charcoal} = \text{Charcoal price} \quad \text{R/yr}
\]

Total revenue firewood

\[
\text{Total revenue firewood} = \text{Firewood price} \quad \text{R/yr}
\]

Total revenue pulp

\[
\text{Total revenue pulp} = \text{Pulp price} \quad \text{R/yr}
\]

Total revenue SSU

\[
\text{Total revenue SSU} = \text{Weight production (SSU)} \times \text{Unit price SSU} \quad \text{R/yr}
\]

Total revenue timber

\[
\text{Total revenue timber} = \text{Timber price} \quad \text{R/yr}
\]

Unit clearing cost

\[
\text{Unit clearing cost} = \text{Budget (DEAK+)} \div \text{Annual alien clearance} \quad \text{R/yr}
\]

Unit reference value

\[
\text{Unit reference value} = \text{Cumulative PV clearing cost} \div \text{Cumulative PV water volume} \quad \text{R/m3}
\]

Utilizable biomass acacia saligna

\[
\text{Utilizable biomass acacia saligna} = \text{Biomass per ha acacia saligna} \times \text{Acacia saligna clearance} \quad \text{ton/yr}
\]

Utilizable biomass Pinus species

\[
\text{Utilizable biomass Pinus species} = \text{Biomass per ha Pinus species} \times \text{Pinus species clearance} \quad \text{ton/yr}
\]
<table>
<thead>
<tr>
<th>Utilizable biomass wattle spp</th>
<th>Biomass per ha wattle spp*Wattle species clearance</th>
<th>ton/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wattle species clearance</td>
<td>(Effect of PD on ha cleared-5612)*Proportion of Wattle species</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Wattle spp regrowth</td>
<td>Area Wattle spp*Spread rate Wattle spp</td>
<td>ha/yr</td>
</tr>
<tr>
<td>Weight production (SSU)</td>
<td>SSU weight production: Commercial<strong>Ha grazed: SSU</strong></td>
<td>kg/yr</td>
</tr>
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### Appendix B: System dynamics validity tests

<table>
<thead>
<tr>
<th>Test</th>
<th>Description</th>
<th>Result</th>
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<tbody>
<tr>
<td>Structure verification test</td>
<td>Tests the internal structure of the model</td>
<td>Pass</td>
</tr>
<tr>
<td>Dimensional consistency</td>
<td>Tests the unit uniformity of all model equations</td>
<td>Pass</td>
</tr>
<tr>
<td>Parameter verification</td>
<td>Tests the constant variable in the model against literature</td>
<td>Pass</td>
</tr>
<tr>
<td>Extreme condition</td>
<td>Evaluates the plausibility of extreme values and the model generated behaviour versus real life behaviour</td>
<td>Pass</td>
</tr>
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</table>