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A cost-benefit analysis of clearing invasive alien plants in the Berg River quaternary catchment of South Africa

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Abstract

Environmental degradation caused by invasive alien plants must be remedied in time before the land becomes too heavily degraded for restoration to be successful. This study investigates the cost-benefit analysis of restoring natural capital through clearing invasive alien plants and transforming them into value-added products (VAPs), such as wood chips, timber, firewood, charcoal and briquettes, under three scenarios using a system dynamics modelling approach. The study shows that, if the production of VAPs commenced in 2015, the net present value (NPV) under all scenarios (namely clearing activities paid for by the government alone, clearing activities with 20% co-financed by the private sector, or the do-nothing scenario) resulted in negative values. If, however, the production of VAPs had commenced from the beginning of the model simulation (2008), the cumulative NPV for both the government-funded clearing activities scenario and the 20% private sector co-finance scenario is strongly positive (higher than ZAR200 million).

Key words: restoration; natural capital; cost-benefit analysis; invasive alien plants; value-added products; system dynamics modelling

1. Introduction

Since the Working for Water (WfW) programme was established and implemented in 1996 (Van Wilgen *et al*. 1997; Working for Water Programme [WfW] 2000; Binns *et al*. 2001; Dye & Versfeld 2007), the diverse negative effects of invasive alien plants (IAPs) have been widely recognised and clearing operations have been intensified from a national-scale perspective. This has been driven by the expanded public works programme (EPWP). The programme's comprehensive approach to IAP control is characterised by a number of unique features, comprising combined chemical and mechanical control of IAPs in targeted areas by employing underprivileged people as the task force. This is complemented by the expansion of biological control options that target priority IAP species (Moran *et al.* 2005), the encouragement of payment for ecosystem services in order to raise funds to support control programmes (Turpie *et al.* 2008), and the promulgation of legislation that compels landlords to address the IAP problem (Van Wilgen *et al.* 2011). Given the intense competition for the fiscal budget (for example, the protests by tertiary students demanding free education), it is imperative for the WfW programme to motivate and justify why the government should continue to fund the various natural resource management projects undertaken by the Department of Environmental Affairs in South Africa (Nkambule *et al.* 2016).

Several studies have attempted to investigate the economic analysis of clearing IAPs (Van Wilgen *et al.* 1996; Higgins *et al.* 1997a, 1997b; Van Wilgen *et al.* 1997; Heydenrych 1999; Hosking & Du Preez 1999; Turpie & Heydenrych 2000; Van Wilgen *et al.* 2000; De Wit *et al.* 2001; Le Maitre *et al.* 2002; McConnachie *et al.* 2003; Van Wilgen *et al.* 2004; Currie *et al.* 2009; De Lange & Van Wilgen 2010; Mwebaze *et al.* 2010; Wise *et al.* 2012; Mugido *et al.* 2014). However, these studies underestimate the costs and benefits of clearing IAPs due to their failure to consider the value of ecosystem goods and service, and the opportunity cost of not clearing IAPs. The economic valuation of ecosystem goods and services has been widely emphasised as a way to promote pro-conservation and environmental initiatives (Bishop 1978; Van Wilgen *et al.* 1996; Pagiola *et al.* 2002; Blignaut & De Wit 2004; Pagiola & Platais 2007; Turpie *et al.* 2008). In addition, the valuation of ecosystem goods and services has been acknowledged in the international literature (Costanza *et al.* 1997; Millennium Ecosystem Assessment [MEA] 2005; Daily *et al.* 2009; De Groot *et al.* 2010) as a good way to evaluate the costs and benefits of management programmes (like the WfW and other natural resources management programmes). The cost-benefit analysis of clearing IAPs is necessary to investigate the role played by economics in the restoration activities within the Berg River catchment in the Western Cape province of South Africa.

This study seeks to address the question whether the benefits of restoration through clearing IAPs and transforming them into value-added products (VAPs) (and including water saved) outweigh the clearing costs incurred. This will be done by taking a system dynamics modelling approach to investigate the costs and benefits of clearing IAPs and transforming them into VAPs under different scenarios.

2. Site description

This research was conducted in the quaternary catchments ($G10_{A-J}$) of the Berg River catchment in the Western Cape province, South Africa (see Figure 1). According to De Villiers (2007), the Berg River is approximately 294 km in length, with a catchment area amounting to 7 715 km^2, eventually depositing its waterflow into the Atlantic Ocean. The specific quaternary catchment areas under investigation constitute 3 286 km^2 (Department of Water and Sanitation [DWS] 2015) of the total catchment area.

In terms of climate, the Berg River catchment receives a mean annual rainfall of 500 to 2 000 mm. This site falls within the fynbos biome (Mucina & Rutherford, 2006). Concerning the geology, the catchment is characterised by Cape granites and Malmesbury shale rocks (with the exception of the upper catchments, which are dominated by sandstone and quartzite rocks of the Cape super group) (De Villiers 2007). In terms of the pedological profile, the Berg River catchment consists mainly of unfertile lithological soils, with some parts of the catchment characterised by deep alluvial flood plains and nutrient-rich soil deposits (De Villiers 2007). As for the hydrological features, the Berg River's flow peaks during the period between June and August as a result of the winter rainy season of the Mediterranean climatic conditions experienced within the catchment (Mucina & Rutherford 2006). The quaternary catchments from the study site have a total population size of 302 955 people, with a population density of 9 218 people per km^2, an average population growth rate of 3.06% and a total workforce of 161 251 people (Statistics South Africa [Stats SA] 2011). The settlement type is two-pronged, with 31.84% as farm settlements and 67.16% as urban settlements. In terms of human capital development, 3.18% of the people are without schooling, 92.46% either have some primary school education or have completed primary education, and 4.36% have completed higher education (Stats SA 2011).

According to Kotzé *et al*. (2010), the major IAPs within the study site in the Berg River catchment are *Pinus* species, *Eucalyptus* species, *Acacia* species (*A. cyclops* and *A. mearnsii*) and other wattle species. The uncondensed and condensed areas invaded by these species are shown in Table 1. The clearing of IAPs is a standard technique in the catchment management plan currently implemented by various contractors funded by the WfW programme through the Department of Environmental Affairs. In the various quaternary catchments within the investigation site, 19 981 contracts have been signed and 1 066 contractors have been appointed to undertake the clearing operations for the period 2008 to 2014 (Department of Environmental Affairs [DEA] 2015). In most of the areas, IAPs are cleared in phases using a combination of mechanical and chemical clearing (E de Kocker, personal communication 2015; G Pitseng, personal communication 2015). Owing to the re-growth of shoots from the felled IAP tree stumps, follow-up clearing is done until the polygons under control have been passively restored. Only then do the contractors move on to clear other invaded polygons within the catchment.

Table 1: Invasion status within the Berg River catchment areas (G10$_{A\text{-}J}$): 2008

Invasive alien plants	Uncondensed hectares*	Condensed hectares*
Pinus species	14 632	4 883
Eucalyptus species	13 671	1 641
Acacia cyclops	7 213	890
Acacia saligna	9 158	850
Wattle species (mainly *A. mearnsii*)	127	376

*All hectares are rounded off to the nearest whole number
Source: Own analysis of results adapted from Kotzé *et al*. (2010)

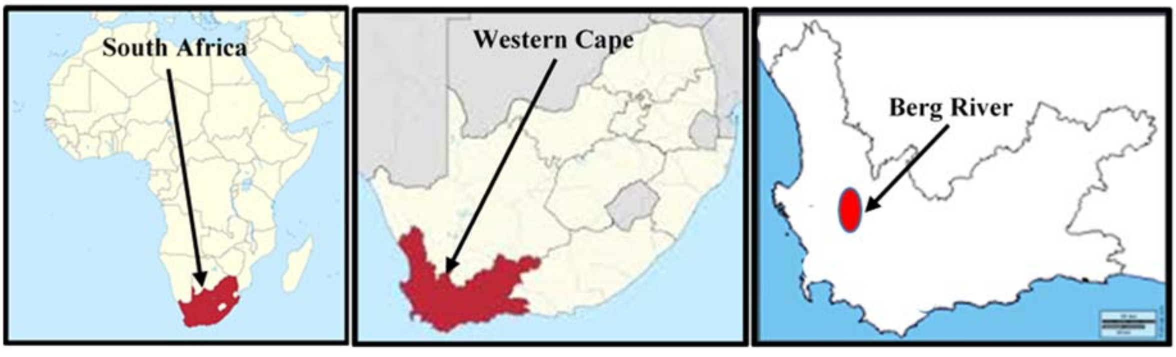

Figure 1: Location map of the Berg River catchment in the Western Cape, South Africa
Source: Own adaptation

3. Method

3.1 Research objectives

This research investigates the total (i.e. both private and public externality) costs and benefits of restoring natural capital through clearing IAPs and using cleared IAPs biomass to produce VAPs such as wood chips, firewood, timber, charcoal and briquettes versus doing nothing. This is done in order to determine whether or not the benefits (of both VAPs and water saved) outweigh the costs (i.e. clearing costs, VAP manufacturing costs and carbon sequestration losses). In addition, this research determines the economic feasibility of setting up value-added industries that produce VAPs from the standing stock that is cleared in the Berg River catchment areas considered. Moreover, the research sought to investigate the prospective impacts of the DEA's clearing efforts on the area invaded by IAPs. These research objectives were also further tested against different scenarios (see Section 4.1) to determine possible policy interventions that might yield the best possible results.

3.2 Data collection

The data utilised in this study was collected from multiple sources. First, the data on the invasion status (i.e. IAP densities, areas under invasion and IAPs species invading the sites) of the quaternary catchment under study was obtained from the DEA: NRM database. This data was recommended by the DEA: NRM projects manager for the Berg River catchment as the latest available information derived from the National Invasive Alien Plant Survey conducted by Kotzé *et al.* (2010). Moreover, a ground-truthing exercise (through a personal site visit) was undertaken to verify whether or not the IAPs contained in the DEA: NRM database actually existed within the site. The major limitation regarding the aforementioned data is the fact that the survey done by Kotzé *et al.* (2010) was conducted in 2008 and only published in 2010. As a result there might have been some changes to the invasion status in the site; however, to our knowledge there is no other data available besides that published by Kotzé *et al.* (2010). The data for person days, together with the clearing budget, was also obtained from the DEA: NRM database and was confirmed to be accurate by the DEA Western Cape projects manager. The data used to assess water consumption, carbon sequestration and value-added products was obtained through extensive literature surveys, focus group discussions, interviews and consultation with experts (for verification and validation). Last but not least, the publications and website of Statistics South Africa were utilised to obtain information on the population and demographic characteristics (see Section 2).

3.3 Conceptual model

A system dynamics model (RESTOREBERG model) was constructed and used to analyse the costs and benefits of clearing IAPs and transforming them into VAPs (wood chips, firewood, timber, charcoal and briquettes). The spread of IAPs is the main disturbance that affects the Berg River catchment. The major IAPs affecting the study area are mentioned in Table 1. These non-indigenous IAPs pose a significant threat to the environment (Adair 2000; Le Maitre *et al.* 2000; De Wit *et al.* 2001; Bustamante & Simonetti 2005; Van Wilgen *et al.* 2008) through the reduction in stream flow runoff, allelopathic effects, increased water consumption, loss of grazing capacity, increased fire risks and loss of biodiversity, to mention a few. However, despite these harmful effects, IAPs are also useful and of relative importance in providing VAPs such as woodchips, firewood, timber, biomass for electricity generation, charcoal and timber. They also provide positive externality benefits such as carbon sequestration, enhancing the functioning of the hydrological cycle, overwintering pollination bees (which are an important factor for the South African deciduous fruit industry), and the fixation of nitrogen (Richardson 1998; De Wit *et al.* 2001; Marchante *et al.* 2004; Richardson & Petit 2005).

The custom-built RESTOREBERG model consists of six sub-models, namely the land use sub-model, the VAPs sub-model, the water savings sub-model, the carbon sequestration sub-model, the clearing cost sub-model and the economic sub-model (see Figures A1 to A6 in Supplementary material, Annexure 1). The simulation period for this model is 2008 to 2030, with 2008 being the base year given the fact that the data available for the distribution and spread of IAPs dates from 2008 (see Table 1). The Supplementary material shows the model boundary chart (Table A1, Annexure 2), the model parameters and equations used in the RESTOREBERG model (Table A2, Annexure 3), the causal loop diagram (Figure A7, Annexure 4), and the cost and benefit results summary tables (Tables A3 to A10, Annexure 5).

3.4 RESTOREBERG model scenarios

The RESTOREBERG model was run for three main scenarios, with two having an "a" and a "b" part to assess whether there are any uncertainties regarding the expected results from the model simulation and the respective policy implications. The first scenario (DEA B) assumes that all the clearing operations are funded by the Department of Environmental Affairs (DEA) budget alone. The second scenario (DEA B+) assumes the IAP clearing operations are funded by both the DEA and a co-finance option of 20% from the private sector. The third scenario is the baseline scenario and assumes that clearing operations are done from 2008 till 2014, after which no clearing happens until 2030. These scenarios are presented in Table 2.

Table 2: Scenarios considered

Scenario	**Brief description**
1a DEA B	Clearing activities from 2008 to 2014, then continued clearing interventions at 2014 levels from 2015 onwards. The clearing operations are funded by the DEA budget alone. The manufacture of VAPs begins from the year 2015 onward.
1b DEA B (with VAPs from the start, i.e. 2008)	Similar to scenario 1(a), except that the manufacture of VAPs begins from the year 2008 onward.
2a DEA B+	Similar to the DEA B scenario. In addition, operations are funded by both the DEA and the private sector (a 20% co-finance option commencing in the year 2015).
2b DEA B+ (with VAPs from the start, i.e. 2008)	Similar to scenario 2(a), except that the manufacture of VAPs and the 20% co-finance begin from the year 2008 onward.
3 Baseline scenario	Baseline scenario: Clearing operations are done from 2008 to 2014 and after that no clearing interventions happen. Clearing operations are funded by the DEA budget only, and no VAPs are manufactured.

Source: Own analysis

3.5 Model verification and validation

Model validation comprises a continuous series of actions to test and establish confidence in the model, and runs throughout the entire process of model building (Forrester & Senge 1980). The RESTOREBERG model was tested for model debugging, internal structure validity and behaviour validity. This was done to gain confidence in the model structure before running the simulation. The debugging phase was conducted to check for errors and to ensure that the model simulation ran properly without any problems. Basically, model debugging involves the investigation of any possible errors within the model without any knowledge pertaining to their presence (Pruyt 2013). The RESTOREBERG model does not have any errors.

The second test conducted was the structural and behaviour validity test. This test was performed in order to establish the validity of the internal structure of the RESTOREBERG model. The model structure was compared to the real-world system, as evidenced in the reference model (i.e. historical trend in the real world as reported in the literature). The structural validity test consists of four tests, namely structure verification, dimension consistency, parameter verification and extreme condition (Forrester & Senge 1980; Sterman 2000; Zebda 2002).

The structure verification test compared the structure of the RESTOREBERG model against the structure of the real-world system. It was found to be consistent with the trend observed in the real-world system. The dimensional consistency test was performed to check for unit uniformity for all the equations used in the RESTOREBERG model. All the units and equations were examined and found to be dimensionally consistent and correct. The parameter verification test was done to check if the RESTOREBERG model's conceptual and numerical evaluation of constants matched that of the real-world system. All the values for the data parameters used in the RESTOREBERG model were obtained from the existing knowledge of the real-world system and available quantitative data on IAPs in South Africa. These are presented in Table A2 (Annexure 3). Finally, the extreme condition test was done by assigning extreme values to selected parameters (e.g. the DEA B and DEA B+ budgets) in the RESTOREBERG model. This was dome to check the behaviour of the model against the real-world system. The model outcome for this extreme condition for the clearance of *Eucalyptus* species is presented in Figure 2.

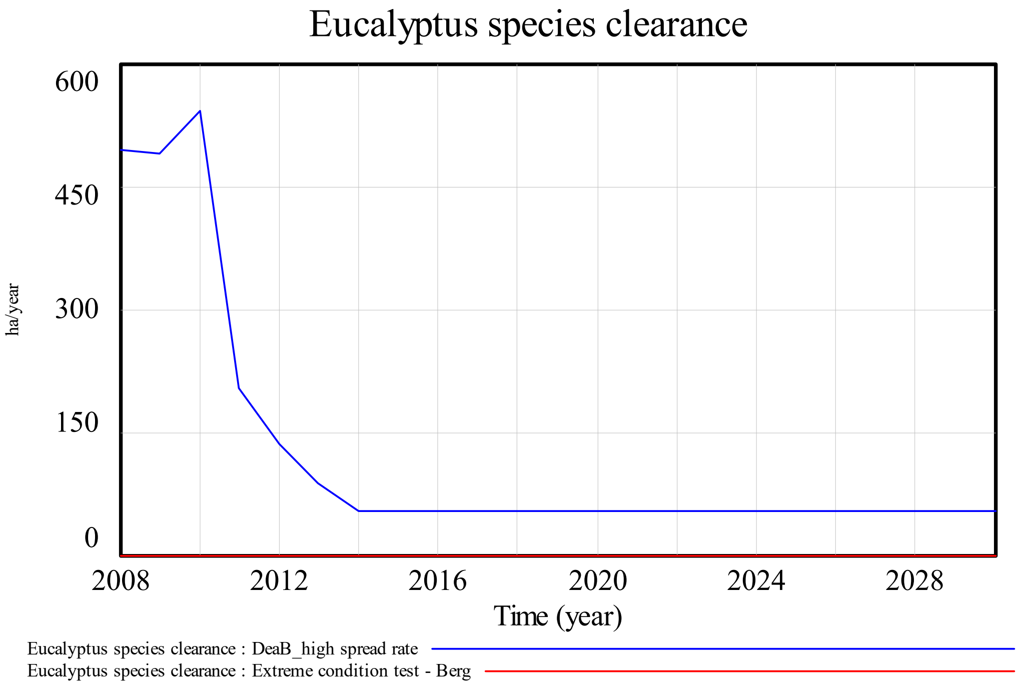

Figure 2: Behaviour of RESTOREBERG model under extreme condition test

Source: Own analysis

4. Results

4.1 State of invasion and clearance activities

The results of the RESTOREBERG model simulation show the baseline values for the annual clearance efforts for the period 2008 to 2014, based on the DEA budget. The area cleared was the same per annum for scenarios 1a, 1b, 2a and 3, within the same period (i.e. 2008 to 2014). However, it was different for scenario 2b due to the assumption of the 20% co-finance commencing at the beginning of the model simulation. In the initial simulation period (i.e. 2008), the area cleared amounted to approximately 2 598 ha, and 277 ha in the year 2014 for all the scenarios (except for scenario 2b) under investigation. Thereafter, the hectares cleared remained at 277 ha for scenarios 1a and 1b (owing to the absence of private sector co-finance), while for scenario 2a the area cleared increased to 321 ha per annum until the end of the model simulation. The results of scenario 2b show that, had the 20% co-finance option commenced at the beginning of the model simulation, the area cleared of IAPs would be close to zero by the year 2015, since they would have been brought under control. As for the baseline scenario, the area cleared reduced to zero by the end of the model simulation owing to the do-nothing assumption. The annual invaded area cleared in the Berg River quaternary catchment areas considered is presented in Table 3.

Table 3: Area cleared per annum in the Berg River catchment areas

Time (Year)	DEA B scenario 1a (Ha/year)	DEA B scenario 1b (Ha/year)	DEA B+ scenario 2a (Ha/year)	DEA B+ scenario 2b (Ha/year	Baseline scenario 3 (Ha/year)
2008	2 598	2 598	2 598	4 711	2 598
2009	2 578	2 578	2 578	4 668	2 578
2010	2 856	2 856	2 856	1 339	2 856
2011	1074	1 074	1 074	201	1 074
2012	711	711	711	30	711
2013	462	462	462	5	462
2014	277	277	277	1	277
2015-2030	277	277	321	0*	0

Source: Own analysis

* For Scenario 2b (i.e. the DEA B+) from 2015 to 2030, all values produced by the RESTOREBERG model simulation are not significant as they are all below 0.5 hectares and were thus rounded off to the nearest whole number.

The area under IAP invasion in the period 2008 to 2014 represents the baseline values, given the historic clearing activities within the Berg River area. At the beginning of the model simulation (i.e. 2008), the total area invaded by IAPs amounted to approximately 8 368 ha for all the scenarios and to 3 204 ha (in the year 2014) for scenarios 1a, 1b, 2a and 3. As for scenario 2b, the area invaded by IAPs amounted to approximately 1 ha in the year 2014, and from 2015 onward it reduced to almost zero until the end of the simulation. With respect to the other scenarios, the area invaded increased over time, with approximately 27 724 ha in scenario 3, 12 447 ha in scenarios 1a and 1b and 14 543 ha in scenario 2a being invaded by the end of the simulation period. The dynamic growth trend of the area invaded is illustrated in detail in Figure 3 for all the scenarios under investigation.

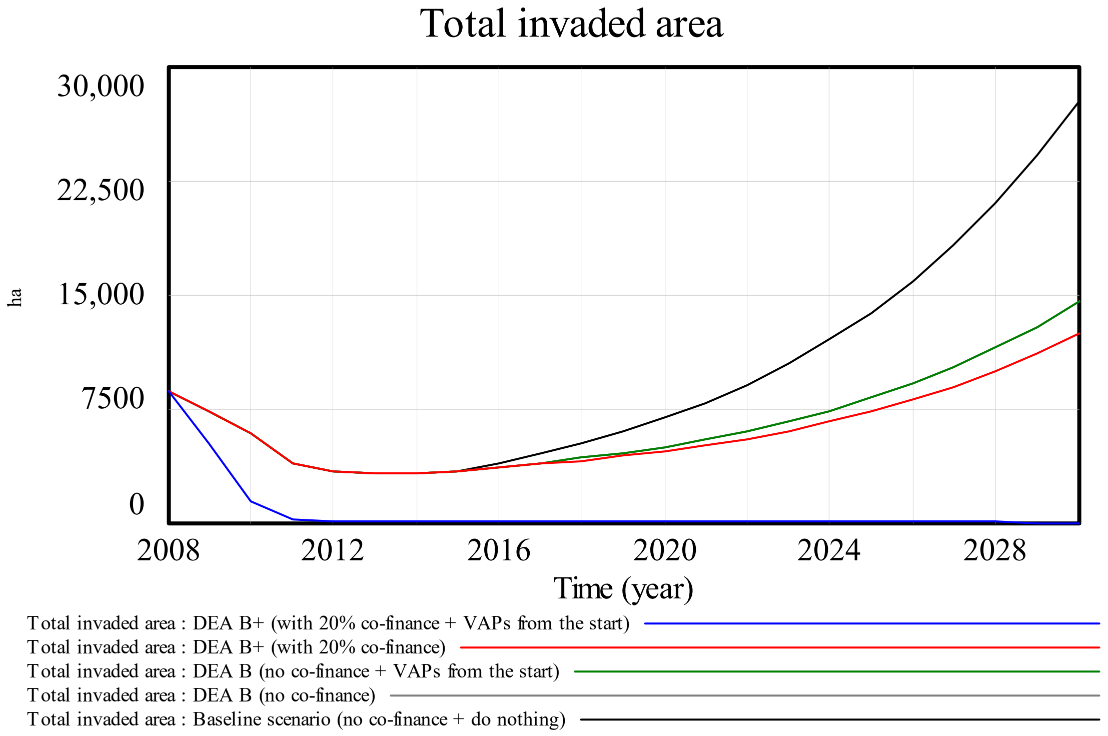

Figure 3: Dynamic behaviour of the area invaded over time

Source: Own analysis

4.2 Costs of IAP management

4.2.1 Total clearing costs

The RESTOREBERG model shows that the total clearing cost for clearing IAPs in the Berg River catchment amounted to approximately ZAR8.5 million in the initial simulation period (2008) for all the three scenarios (except for scenario 2b). As for scenario 2b, the clearing costs amounted to approximately ZAR10.2 million, the increase reflecting the 20% co-finance as per the scenario assumption. By 2010, the clearing cost had increased to ZAR8.7 million for scenarios 1a, 1b, 2a and 3, while for scenario 2b it was approximately ZAR10.5 million. However, by 2014, the total annual clearing cost had decreased to approximately ZAR2.5 million for scenario 2b and to ZAR2.1 million for all the other scenarios. From 2015 until the end of the simulation (2030), the total annual IAP clearing cost remained constant at approximately ZAR2.1 million for scenario 1a and 1b, and ZAR2.5 million for scenario 2a. As for scenario 2b, the total clearing costs were the same as those for 2a until 2021, and thereafter became zero. As for the baseline scenario (scenario 3), the cost is zero (2015 to 2030). The total IAP clearing cost per annum for the entire simulation period (2008 to 2030) is presented in the Supplementary material (Table A8 in Annexure 5) for all scenarios.

4.2.2 Total manufacturing costs: Value-added products

The total manufacturing costs of all VAPs (i.e. wood chips, firewood, timber, charcoal and briquettes) considered amounted to approximately ZAR33.1 million for scenario 1a and ZAR38.4 million for scenario 2a respectively for the period 2015 to 2030. Before 2015, the total manufacturing costs were zero owing to the absence of VAP production. As for scenarios 1b and 2b, the total manufacturing costs presented for the period 2008 to 2014 (see Supplementary material – Table A8, Annexure 5) represent the costs that would have been incurred had the production of VAPs commenced together with the clearing efforts in 2008. As for the baseline scenario, the total manufacturing costs remained zero throughout the simulation period due to the do-nothing assumption. The total manufacturing costs for VAPs are also presented in the Supplementary material (Table A8 in Annexure 5) for all the scenarios.

4.2.3 Carbon sequestration loss

The results emanating from the RESTOREBERG model show that the carbon sequestration loss per annum due to clearing IAPs was identical for all scenarios (except scenario 2b) for the period 2008 to 2014. The annual values emanating from this period represent the baseline values based on the historical clearing activities undertaken by the DEA through its Working for Water programme. The net carbon sequestration loss amounted to 141 259 tonnes in 2008, valued at ZAR16.9 million, and to 13 104 tonnes in 2014, valued at approximately ZAR1.6 million, for scenarios 1a, 1b, 2a and 3. For scenario 2b it amounted to approximately 262 655 tonnes in 2008, valued at ZAR31.5 million, and 38.2 tonnes in 2014, valued at ZAR4 585. Thereafter, the value of the carbon sequestration loss decreased over time, with 7 691 tonnes, valued at ZAR922 940 for scenario 2a, and 3 370 tonnes, valued at ZAR404 374 for scenarios 1a and 1b, being lost at the end of the simulation (i.e. 2030). As for scenario 2b, the carbon sequestration loss reduced to 5.7 tonnes in 2015, valued at approximately ZAR688. Thereafter, the losses reduced to almost zero by 2019 and continued in that vein until the end of the model simulation. However, for scenario 3, the net carbon sequestration loss turned negative (meaning a net carbon sequestration gain) from 2015 onwards until the end of the simulation period. In 2015, the net carbon sequestration gain amounted to approximately 2 925 tonnes of carbon, valued at -ZAR350 990, ending with 23 800 tonnes of carbon in 2030, valued at -ZAR2.9 million. In technical terms, these negative monetary values represent a net carbon sequestration benefit. This is due to the absence of clearing activities from the year 2015 onwards (meaning zero carbon sequestration loss), and as a result the re-invasion by the IAPs has a beneficial effect emanating from the photosynthetic process by which IAPs use carbon dioxide from the atmosphere. The results of the carbon sequestration monetary value losses are illustrated in the Supplementary material (Table A9 in Annexure 5) for all the scenarios.

4.3 Monetary valuation of benefits

4.3.1 Water saved due to clearing IAPs in the Berg River

The amount of water saved as a result of clearing IAPs in the Berg River catchment was found to be 4.9 million m^3 in the initial simulation period (2008) (for scenarios 1a, 1b, 2a and 3) and 8.9 million m^3 for scenario 2b. The water savings due to IAP clearance further increased during the period 2008 to 2010 and were reported to be approximately 5.4 million m^3 for scenarios 1a, 1b, 2a and 3 in 2010. A decrease was noted for scenario 2b, amounting to 2.5 million m^3 – this was as a result of the declining stock of IAPs harvested. By 2014, the amount of water saved gradually decreased to an estimated figure of 525 676 m^3 for scenarios 1a, 1b, 2a and 3 and 1 286 m^3 for scenario 2b. As from 2015 until 2030, the approximate amount of water saved annually remained constant, at 525 676 m^3 for scenarios 1a and 1b and 609 285 m^3 for scenario 2a. For scenario 2b, the amount of water saved amounted to approximately 193 m^3 in 2015, and thereafter it decreased to almost zero by 2019 until the end of the simulation period. As for the baseline scenario (scenario 3), the amount of water saved was zero for 2015 to 2030.

Using a conservative unit value of ZAR2/m^3, the value of water saved by clearing IAPs in the Berg River catchment study areas amounted to approximately ZAR9.9 million for the initial simulation period (2008) for scenarios 1a, 1b, 2a and 3, and to ZAR17.9 million for scenario 2b. This amount increased during 2009 and 2010, to ZAR9.8 million and ZAR10.8 million respectively for scenarios 1a, 1b, 2a and 3, while for scenario 2b it decreased to ZAR17.7 million and ZAR5.1 million respectively. For 2011 to 2014, this value decreased by ZAR1.4 million in 2012 and ZAR942 666 in 2013, and the value of water saved was approximately ZAR1.1 million in 2014 for scenarios 1a, 1b, 2a and 3. As for scenario 2b, the value of water saved declined from ZAR114 330 in 2012 to ZAR2 572 in 2014, as most of the IAPs would have been cleared. From 2015 to 2030, the value of water saved remained constant, at approximately ZAR1.1 million per annum for scenarios 1a and 1b and ZAR1.2 million per annum for scenario 2a, while for scenario 2b the water savings value continued to decrease, with no significant water savings from 2019 onward. As for the baseline scenario (scenario 3), no water was saved due to the halting of clearing activities, and therefore the value remained constant, at zero, from 2015 to 2030. These results are presented in the Supplementary material (Table A10 in Annexure 5).

4.3.2 Net income from VAPs produced

The results of the RESTOREBERG model show positive net income outputs for all the VAPs considered for the scenarios 1a, 1b, 2a and 2b. However, for the baseline scenario, the net income was zero for all VAPs due to the do-nothing scenario over the whole simulation period. Moreover, the net income for scenarios 1a and 2a was zero for both scenarios from 2008 to 2014 due to the absence of VAP production. The production operations of VAPs are assumed to have commenced in 2015, running until the end of the simulation period for these respective scenarios. It is important to note that a conservative assumption of a 20% profit margin was used to derive the net income values for the VAPs considered. However, for scenarios 1b and 2b, the production of VAPs was assumed to have commenced in 2008. This was done in order to show the opportunity cost of income forgone in the period 2008 to 2014, when historical clearing efforts happened without any value addition to the cleared IAP biomass. The total net income from VAPs amounted to approximately ZAR8.2 million per annum for scenario 1a and ZAR9.6 million per annum for scenario 2a from the year 2015 until the end of the model simulation. As for scenarios 1b and 2b, the net income forgone, had the production of VAPs commenced right from the beginning, is shown in the Supplementary material (Table A10 in Annexure 5) for the period 2008 to 2014). Thereafter, the total net income for scenario 1b would have remained the same as that for scenario 1a, while for scenario 2b the income would have decreased to ZAR3 041, reaching zero by the year 2020, owing to less/no biomass being available for the manufacture of VAPs. The total combined net income values from the manufacture and sale of VAPs considered are presented in the Supplementary material (Table A10 in Annexure 5). The individual net income values of VAPs produced are presented in the Supplementary material (Tables A3 to A7 in Annexure 5).

4.4 Cost benefit analysis

4.4.1 Net present value (NPV)

The NPV[1] method is commonly used when determining the feasibility of undertaking a project to help decision makers choose the best possible alternative and to avoid alternatives that are likely to fail. Using a discount rate of 6%, the annual benefits and costs were discounted to investigate whether or not clearing IAPs and transforming their biomass into VAPs was a feasible option subject to the scenarios considered.

4.4.2 Cumulative NPV (with externalities included)

Given the aforementioned, the RESTOREBERG model results showed negative cumulative NPVs for scenarios 1a, 2a and 3. These were shown to be approximately -ZAR21.4 million for scenario 1a, -ZAR16.8 million for scenario 1b and -ZAR53.7 million for scenario 3 for the entire simulation period (2008 to 2030). However, the cumulative NPV for scenarios 1b and 2b was positive over the entire simulation period, amounting to ZAR248.8 million for scenario 1b and ZAR215.8 million for scenario 2b. These values are summarised in Table 4.

4.4.3 Cumulative NPV (without externalities)

From a partial analysis perspective (excluding externalities, i.e. water savings benefits and carbon sequestration losses), the cumulative NPV was positive for all scenarios, except for the baseline scenario, which was still negative. We report the cumulative NPV to be approximately ZAR4.7 million for scenario 1a, ZAR275 million for scenario 1b, ZAR10.5 million for scenario 2a, ZAR244.8 million for scenario 2a and -ZAR35.2 million for scenario 3. These value are also summarised in Table 4.

4.4.4 Unit reference value of water saved due to clearing IAPs

The RESTOREBERG model shows that the unit reference value (URV) of water saved due to clearing IAPs in the study area is greater than 1 for all the scenarios. For the period 2008 to 2010, the annual URV of water saved was constant, at approximately ZAR1.73 per m^3 for all the scenarios. For 2011 to 2030, the annual URV increased gradually, resulting in a final cumulative URV of approximately ZAR2.26 per m^3 for scenarios 1a and 1b, ZAR2.31 per m^3 for scenario 2a, ZAR2.54 per m^3 for scenario 2b and ZAR1.98 per m^3 for scenario 3. The results are summarised in Table 4.

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[1] $NPV = \sum_{T=1}^{T} \frac{B_t}{(1+r)^t} - \frac{C_t}{(1+r)^t}$ (1)

where:
B_t = total annual benefits realised during the year t over a given time period (2)
C_t = total annual costs incurred during year t over a given time period (3)
r = discount rate (4), and
t = year of cost (5)

Table 4: Summary table for the cumulative NPV and URV results

	With externalities included					With externalities excluded				
Scenario	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 3
NPV (ZAR: 000)	-21 416	248 844	-16 842	215 771	-53 684	4 721	274 982	10 510	244 762	-35 182
URV (ZAR/m^3)	2.26	2.26	2.31	2.54	1.98					

Source: Own analysis

5. Discussion

The RESTOREBERG model simulation results show that the current budget of the DEA through its Working for Water programme is not enough to win the battle of IAPs in the Berg River catchment areas subject to the scenarios considered. All the scenarios show an increasing growth pattern over time, with scenario 3 being the worst case, followed by scenarios 1a and 1b, and lastly scenario 2a (see Figure 2). Scenarios 2a and 2b show that the private sector co-finance (i.e. 20%) option can help reduce the area invaded, as is evident from the low invasion density compared to the other scenarios. As shown by the trend in scenario 2b, if the 20% co-finance had commenced together with the clearing activities in 2008, the area under invasion would have been brought under control by 2013, with only minor follow-up activities being required for the remainder of the simulation period. However, starting the 20% co-finance only in 2015 (as in scenario 2a), the total invaded area still proves to be low (compared to scenarios 1a, 1b and 3), despite the increasing growth trend over time (see Figure 2), thus showing good prospects in the fight against IAPs invading the Berg River catchment areas. Given the aforementioned, there is proof that the early restoration of natural capital through the clearing of IAPs is more beneficial than waiting until the area under invasion has been severely invaded.

The results from the RESTOREBERG model show that clearing IAPs in the Berg River catchment areas can lead to significant water savings. The greatest amount of water saved was noted in the period from 2008 to 2010, ranging between 4 929 496 m^3 and 8 939 667 m^3 for the scenarios investigated. This can be attributed to the relatively higher IAP densities cleared during this period. However, as the clearing operations progress, the number of IAP standing stocks significantly decrease, meaning that water consumption by IAPs also significantly decreases. The amount of water saved from 2015 to 2030 remains constant for scenarios 1a, 1b, and 2a due to the assumption that, from 2015 onwards, clearing interventions are done at 2014 levels. However, for scenario 2b, the water saved due to clearance decreases quite quickly, becoming zero by the year 2019, since most of the IAPs would have been cleared and brought under control. In addition, greater quantities of water saved per annum are experienced in scenarios 2a and 2b due to the fact that clearing operations are funded by both the DEA budget and a 20% co-finance from the private sector, resulting in a larger area being controlled compared to the other scenarios, where clearing is done using only the DEA budget. For the baseline scenario, water is only saved from 2008 to 2014; no water savings are realised from 2015 to 2030. This is due to the assumption that clearing operations will end in 2014 (scenario 3). No water will be saved and, as re-invasion by IAPs happens, more water will actually be consumed by the IAPs. However, we could not quantify this due to a lack of data on the water consumption emanating from the annual re-growth of IAPs. It therefore is imperative that scenario 3 is avoided by all means possible. Scenarios 1a, 1b, 2a and 2b are better options, with scenario 2b being the best (as the IAPs are quickly brought under control), considering that South Africa is a water-scarce country. Clearing IAPs will ensure more water supply to the Berg River Dam, and eventually to the City of Cape Town. The risk of water insecurity, which has been worsened by the current drought, can be reduced by following any of the aforementioned recommended scenarios.

The integrated benefits (i.e. including both private and public externality) and costs of clearing IAPs (and transforming the cleared biomass into VAPs) in the Berg River were discounted using a discount rate of 6%. This resulted in a negative cumulative NPV for scenarios 1a, 2a and 3 (see Table 4). However, if the production of VAPs had commenced from the beginning of the model simulation (in 2008), the cumulative NPV for scenarios 1a and 2a would have been positive, as shown by the results for scenarios 1b and 2b. As a result, the difference between the cumulative NPV values shown in scenarios 1b and 2b and those in scenarios 1a and 2a represents the opportunity cost of having forgone the manufacture of VAPs in the period from 2008 to 2014. This opportunity cost amounts to approximately ZAR227.4 million for scenario 1a and ZAR198.9 million for scenario 2a. Moreover, we also reported a positive cumulative NPV from a partial analysis perspective (excluding externalities, i.e. water savings benefits and carbon sequestration losses) for all scenarios except for scenario 3. This is important in order to see how sensitive the cumulative NPV is to the exclusion of the externalities. We found the modelled system to be highly sensitive to the exclusion of externalities, since the previously negative NPV values for scenarios 1a and 2a became positive, while the positive NPV values reported in scenarios 1b and 2b further increased (compared to the analysis that included externalities).

The URV produced by the economic sub-model were greater than 1 for all the scenarios. This indicates that the present value of the costs of clearing IAPs outweigh the present value of benefits of water saved due to clearing IAPs. It is important to note that this URV analysis only considers water-saving benefits and ignores the other benefits derived from clearing IAPs in the Berg River catchment study area. Moreover, if we compare our estimated URV values to the actual URV for the Berg River dam of ZAR2.55/m^3 (based on guidelines), as reported by Preston (2015), ours are much better for scenarios 1a and 1b (ZAR 2.26/m^3) and scenario 2a (ZAR 2.31/m^3), while that of scenario 3 (ZAR 2.54/m^3) is more or less the same as the actual (ZAR 2.55/m^3). Given the aforementioned, these URV results are robust and therefore can inform decision makers on which actions to consider and which to avoid.

6. Conclusions and recommendations

The results generated by the RESTOREBERG simulation model show that transforming IAPs in the Berg River catchment into VAPs (i.e. wood chips, firewood, timber, charcoal and briquettes) is viable from a partial analysis perspective (i.e. ignoring externalities) for all scenarios (except scenario 3). However, from an integrated analysis (i.e. including externalities), only scenarios 1b and 2b show the aforementioned as feasible. Moreover, the current clearing efforts are not enough to avert the problem of invasion by IAPs. As a result, moderate and high co-finance options should be tested to see how the area invaded responds over time.

Despite the results of the RESTOREBERG model, it is important to take cognisance that there are other benefits (/costs) that can be derived (/incurred) from clearing IAPs in the Berg River catchment study area. As shown in the model boundary chart (see the Supplementary material, Annexure 2), this study only modelled the cost-benefit analysis of clearing IAPs and transforming them into VAPs on, *inter alia*, water savings and carbon sequestration losses. As a result, other benefits and costs have been excluded in the model because they were beyond the scope of this study. Moreover, it is important to note that the major objective of the DEA through its Working for Water programme is to get rid of IAPs, which consume excessive amounts of water (which is deemed to be scarce from a national perspective), and not to profit from VAPs made from IAP biomass. Thus, these results only serve as a blueprint pointing out the prospects of converting IAPs into VAPs within the Berg River catchment areas and how this can contribute to the clearing of IAPs.

Further research is needed to investigate the viability of other VAP combinations that could potentially be made from IAPs in the Berg River catchment study area. In addition, other benefits and costs (not considered in this research) emanating from clearing IAPs should be included for a clearer picture of the costs and benefits of clearing IAPs and using them to produce VAPs. Different scenarios and policy interventions should be tested to see which ones will bring about more financial viability for industries using IAPs to make VAPs. Lastly, it is important to take note that this research study does not apply to all catchment sites in South Africa, but only to the Berg River catchment study area. Therefore, this model should be tested on other sites to see whether or not the same results are produced.

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