An economic analysis of different land-use options to assist in the control of the invasive *Prosopis* (Mesquite) tree

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Abstract

The invasive Prosopis *spp. tree is one of the major causes of disturbance affecting the Orange River water management areas in the Northern Cape, South Africa. These disturbances affect natural capital, such as reducing the stream flow of the Orange River, causing a decline in biodiversity of the native Nama Karoo vegetation, consuming excessive water, and invading dryland areas. Therefore, we assessed the economic value of different land-use options following the control of* Prosopis *spp. to prevent re-invasion using a system dynamics model. This study yields positive cumulative NPVs of between ZAR28.3 million and ZAR98.3 billion when co-finance of between 20% and 100% is included to clear the* Prosopis *spp., combined with the productive land use of the cleared land by the private sector. This is in stark contrast to a negative NPV of -ZAR11.6 million when no alternative land-use activity is implemented on the cleared land. This study shows empirically that clearing* Prosopis *spp. and restoring the cleared land for agricultural land-use options is a cost-effective strategy for controlling the invasive* Prosopis *spp. trees.*

Key words: invasive alien plants; opportunity cost; restoration; natural capital; land-use options

1. Introduction

The invasive *Prosopis* spp. (Mesquite) tree is one of the major disturbances affecting the Orange River water management areas in the Northern Cape, South Africa. These disturbances include, for example, the reduction in stream flow and excessive water consumption (Le Maitre *et al*. 2000; Dzikiti *et al*. 2013; Shackleton *et al*. 2014), a reduction in grazing potential and biodiversity losses (Steenkamp & Chown 1996). However, despite these negative impacts, it also has beneficial economic and social benefits, for example fodder for livestock (Felker 1979; Felker *et al*. 2003; Choge *et al*. 2007; Wise *et al*. 2012), shade for humans and livestock (Shackleton *et al*. 2014), and raw materials for many value-added products (Felker 1979; DeLoach 1985; Felker *et al*. 2003;

Bradshaw *et al*. 2004; Blignaut & Aronson 2008). Because *Prosopis* spp. have both negative and positive impacts, their control has become a contentious subject, especially considering biological control in which biological agents are used to kill the tree indiscriminately (Zachariades *et al*. 2011).

This conflict is exacerbated by the fact that *Prosopis* spp. were introduced intentionally, from the late 19th century through to the mid-20th century (Harding 1987; Harding & Bate 1991; Henderson & Harding 1992), as a livestock fodder crop, *inter alia* also to provide shade for livestock (Wise *et al*. 2012). This introduction was done with the support of government policies through subsidies and extension service initiatives (Poynton 1988). During the 1970s, the negative impacts of *Prosopis* spp. became evident as the impacts became more prominent in areas beyond where they initially were introduced. In a study conducted by Vorster (1977) in the Karoo region of South Africa, approximately 186 000 ha were found to be invaded by *Prosopis* spp. The invasion increased to 200 000 ha in the late 1980s (Harding 1987) and, by the year 1998, 1.8 million ha of South Africa were invaded, with 50% of this area being in the Northern Cape province (Versfeld *et al*. 1998). This finding is supported by Van den Berg (2010), who reported that, by 2007, approximately 1.473 million ha were under *Prosopis* spp. invasion in the Northern Cape province, with the extent expected to increase if nothing was done to control its rapid growth (Wise *et al*. 2012; Shackleton *et al*. 2014).

Prosopis spp. are invasive not only in South Africa, but also in Kenya (Muturi *et al*. 2013), Ethiopia (Wakie *et al*. 2016b), Namibia (Schachtschneider & February 2013; Simali personal communication 2016; Sishuba personal communication 2016), India (Kaur *et al*. 2012), Brazil (De Souza Nascimento *et al*. 2014) and the United Arab Emirates (El-Keblawy & Al-Rawai 2007). In its native regions in the Americas (viz. Argentina, Chile, Honduras, Mexico, Peru and USA) it grows in arid and semi-arid environments, but it does not form dense invasive stands such as in its non-native areas (Zimmermann 1991; Pasiecznik *et al*. 2001).

To date, the control efforts undertaken to deal with *Prosopis* spp. have been mainly manual, mechanical, chemical and biological control approaches, but these have had little effect on their growth (Vorster 1977; Harding 1989; Van den Berg 2010). Other control options include the harvesting of the trees for productive use (Shackleton *et al*. 2014; Wakie *et al*. 2016a) and cultural control (Shackleton *et al*. 2014). However, the success of these measures to curb its invasiveness have not been tested widely. The detrimental impact of *Prosopis* spp. is clearly noted in the literature (Poynton 1988; Harding & Bate 1991; Zimmerman 1991; Pasiecznik *et al*. 2001; Admasu 2008; Van den Berg 2010; Wakie *et al*. 2012; Dzikiti *et al*. 2013; Shackleton *et al*. 2014). Only a few studies, however, have tried to calculate the economic costs and benefits of using it productively as a raw material for various value-added products, such as firewood, charcoal, pulp, flour and honey, and for its medicinal properties (Blignaut & Aaronson 2008; Choge *et al*. 2012; Wise *et al*. 2012; Van Wilgen *et al*. 2012; Sato 2013).

This study aimed to assess the contribution of alternative productive agricultural land-use options following clearing as a means to control and inhibit the re-growth of *Prosopis* spp. in the Northern Cape province, with a particular focus on the Orange River water management area. We developed a system dynamics model for this purpose.

2. Study sites: A description

This study was conducted in the Orange River water management areas between Onseepkans (quaternary catchment D81E) and Pella (quaternary catchment D81G) in the Northern Cape province of South Africa.

2.1 Onseepkans (quaternary catchment D81E)

The *Prosopis* spp. invasion in Onseepkans is estimated to cover approximately 601 condensed ha (Department of Environmental Affairs [DEA: NRM] 2016). Onseepkans is a small rural settlement located on the banks of the Orange River (co-ordinates 28.7990°S 19.3167°E) (see Figure 1). The area acts as the border between South Africa and Namibia. The land was initially occupied by a settler and land prospector by trade, named Edwells, and was bought from him by a group of farmers who realised the land's potential for irrigated agriculture. The irrigated crops include table grapes, citrus, lucerne, beans, pomegranates, dates and essential oils (Clarke & Erasmus 2013).

The Onseepkans area lies within the desert biome and is regarded as one of the driest regions in South Africa. It receives rain in summer, with a mean annual precipitation of 116 mm and with a precipitation seasonality (i.e. coefficient of variation) of 69% (Gallaher 2014). The mean annual temperature for the area is 20°C (Gallaher 2014). In terms of the geology, the Onseepkans area consists of the Okiep, Bushmanland, Korannaland and Geelvloer group (Clarke & Erasmus 2013), with the predominant soils being unconsolidated sand, calcrete, calcarenite, aeolinite, conglomerate, clay, silcrete and limestone (Department of Water and Environmental Affairs [DWA] 2009).

The population of Onseepkans stands at approximately 2 090 people comprising 558 households, with a very low population density of approximately 76 people/km^2 (Statistics South Africa [StatsSA] 2011). In terms of gender, women make up 50.24% (i.e. 1 050 people) while men represent 49.76% (i.e. 1 040 people) of the total population. With respect to the population groups, 78.13% (i.e. 1 633 people) of the population is coloured, while 18.95% (i.e. 396 people) is black Africans, while white people represent 1.48% (i.e. 31 people), and Asians and Indians represent 1.43 % (30 people) (StatsSA 2011). Afrikaans is the dominant language and is spoken by 78.13% of the population (StatsSA 2011).

2.2 Pella (quaternary catchment D81G)

Pella (see Figure 1) is a small rural settlement located in the Namaqua (Bushmanland) region of the Northern Cape province. The name originally referred to an oasis found in that area that was historically used by the Khoisan herders. The area is also close to the banks of the Orange River, which forms the border between South Africa and Namibia. Similar to the Onseepkans area, the land in Pella is suitable for the cultivation of table grapes, dates, essential oil crops, lucerne and pomegranates. Extensive livestock agriculture systems are practised, with most smallholder farmers rearing sheep, goats and a few cattle. The areas close to the Orange River are densely invaded by *Prosopis* spp., with 401 condensed hectares having been mapped (DEA: NRM 2016).

Pella also lies in the desert biome, with the same key climatic statistics as Onseepkans (Gallaher 2014). In terms of the geology, Pella consists of the Okiep, Bushmanland, Korannaland and Geelvloer group (Clarke & Erasmus 2013), with the predominant soils being unconsolidated sand, calcrete, calcarenite, aeolinite, conglomerate, clay, silcrete and limestone (DWA 2009).

The population of Pella consists of approximately 2 470 people residing in about 712 households, with a population density of approximately five people/km^2 (StatsSA 2011). There is an even distribution between the number of men and women, with 96.07% of the population being coloured and 97.45% of the population speaking Afrikaans (StatsSA 2011).

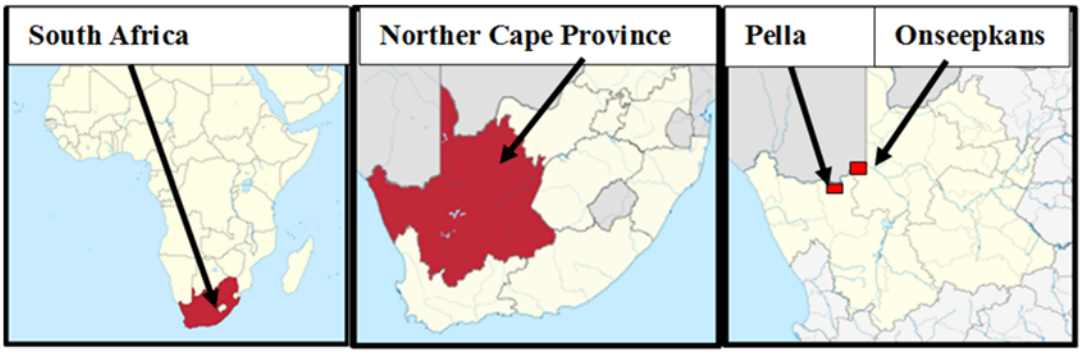

Figure 1: Location of Onseepkans and Pella water management areas (D81E and D81G)
Source: Own analysis

3. Materials and methods

3.1 Data collection

The data for this study was collected from the database of the Natural Resource Management Directorate of the Department of Environmental Affairs (DEA: NRM). The data extracted from this database includes the clearing costs, person days worked, the area invaded by *Prosopis* spp. and the hectares cleared. Extensive literature surveys were also conducted to obtain other published data relevant to this study. Field experts and the relevant DEA: NRM project managers were consulted to validate the data and assumptions. Focus group discussions were held with experts, the DEA: NRM personnel and the clearing operations' implementing agents to aid the qualitative system dynamics model-building process (i.e. the causal loop diagrams). The data pertaining to the alternative land-use options following clearing was obtained from the Bureau for Food and Agricultural Policy (BFAP), Hortgro, VinPro and the South African Table Grape Industry (SATI), and consultation with farmers and experts. This was then supplemented with data obtained from the literature on the respective land-use options. Site visits were also conducted to assist in the ground truthing of the data and the assumptions.

3.2 Data analysis

3.2.1 Method

A system dynamics model (viz. the PROLAND model) was compiled using the Vensim® PLP software. Richardson (1996) defines system dynamics as a computer-aided approach to policy analysis and design related to dynamic problems characterised by complex social, managerial, economic and ecological systems. The interaction between the control methods for invasive alien plants (IAPs), their rate of spread, and the value of alternative land-use options qualifies as such a complex system and therefore system dynamics modelling is applied here. The PROLAND model is described in much greater detail in Part A of the Supplementary Materials. The model parameters and equations used are shown in Part B, while the model validation is described in Part C.

3.2.3 Model scenarios

Four scenarios were developed to assess the impact of clearing *Prosopis* spp. and converting the cleared land to four land-use options (viz. table grapes, raisins, citrus and natural vegetation) over a 23-year (2008 to 2030) simulation period.

Scenario 1 (with 0% co-finance): Business as usual
Here we assume that clearing interventions are conducted by the DEA: NRM from 2008 until 2015, based on historic figures. From 2016 onwards, clearing interventions are continued at 2015 levels, with none of the land being used productively.

Scenario 2 (with 20% co-finance): Low co-finance
Here we assume that clearing interventions are conducted by the DEA: NRM between 2008 until 2015, based on historic figures, but we allow for a 20% co-finance of the clearing operations by the private sector to augment the DEA: NRM budget. The co-finance starts from 2016 onward, with clearing interventions continued at 2015 levels. The cleared land is put to productive agricultural use.

Scenario 3 (with 50% co-finance): Moderate co-finance
Similar to scenario 2, except that the co-finance is at 50%.

Scenario 4 (with 100% co-finance): High co-finance
Similar to scenario 2, except that the co-finance is at 100%, essentially doubling the clearing effort.

4. Results

4.1 Clearing *Prosopis* spp.

The results of the PROLAND model show that invasion by *Prosopis* spp. remains pronounced over the whole simulation period for the baseline scenario (i.e. do nothing + 0% co-finance). The initial condensed area under *Prosopis* spp. invasion was approximately 1 001 ha at the beginning of the model simulation in the year 2008, and remained more or less the same over the entire simulation period, with invasions dropping to 900 ha from the year 2026 until the end of the model simulation. As for scenarios 2, 3 and 4, where the cleared land is converted to productive land-use options and there is co-finance from private land users, the area under invasion immediately starts to decrease, with invasion becoming zero by 2025 for Scenario 2 (with 20% co-finance), by 2024 for Scenario 3 (with 50% co-finance) and by 2023 for Scenario 4 (with 100% co-finance). The dynamic behaviour over time for the area invaded by *Prosopis* spp. is illustrated in Figure 2.

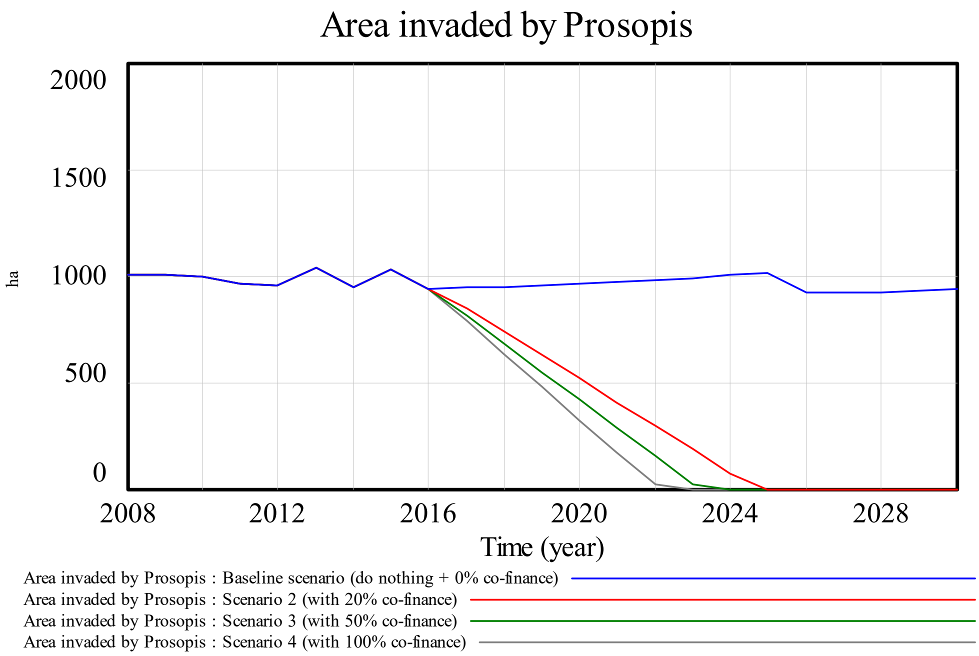

Figure 2: The area cleared of *Prosopis* spp.
Source: Own analysis

4.2 Area restored to active land-use options

The results of the PROLAND model simulation show that the area restored to active land-use options grows in a linear fashion until the maximum restoration area threshold is reached, with approximately 28 ha, 33 ha and 38 ha being restored for scenarios 2, 3 and 4 respectively in year 2016, when restoration commences. Thereafter, the maximum area restored to agricultural land uses is between approximately 234 ha and 241 ha for scenarios 2, 3 and 4. The maximum area restored to agricultural land-use options is reached in the year 2023 (for Scenario 4 with 100% co-finance), 2024 (for Scenario 3 with 50% co-finance) and 2025 (for Scenario 2 with 20% co-finance.) As for the baseline scenario, no restoration to agricultural land use occurs as a result of the "do nothing" assumption. As for the area restored to natural vegetation (i.e. area restored to conservation), the same trend is noticed. However, the maximum area restored to natural vegetation is between approximately 134 ha and 137 ha as a result of continued *Prosopis* spp. re-growth within the area apportioned to natural vegetation. The maximum area restored to natural vegetation is achieved in the years 2025, 2024 and 2023 for Scenarios 2, 3 and 4 respectively, and remains constant until the end of the model simulation. The dynamic behaviour over time for the area restored to all active land-use options considered in this study is illustrated in Figure 3.

4.3 Private benefits and costs of clearing *Prosopis* spp. and restoring to land-use options

4.3.1 Private benefits

Net revenue from table grape land-use option

The results of the PROLAND model show negative net revenue values over the period 2017 to 2022 for the table grape land-use option. In the year 2017, a net revenue loss of approximately -ZAR6.9 million (Scenario 2 with 20% co-finance), -ZAR8.1 million (Scenario 3 with 50% co-finance) and -ZAR9.5 million (Scenario 4 with 100% co-finance) was incurred. The net revenue loss increased over time as more area was cleared and brought under restoration to table grape farming, with approximately -ZAR14.9 million, -ZAR17.6 million and -ZAR20.6 million being incurred in the year 2020 for Scenarios 2, 3 and 4 respectively. Thereafter, the net revenue loss started to decline as the maximum restoration area was reached, with approximately -ZAR3.5 million (Scenario 2), -ZAR4 million (Scenario 3) and -ZAR4.8 million (Scenario 4) being incurred in the year 2022. Thereafter, positive net revenue values are realised for the remainder of the simulation period, with a maximum net revenue of ZAR48.4 million being realised from 2027 onward for Scenario 4, of ZAR48.6 million from 2028 onward for Scenario 3, and of ZAR49.7 million from 2029 onward for Scenario 2.

Net revenue from raisins land-use option

The net revenue results for the raisins land-use option are also negative for the period 2017 to 2021, and follow the same trend as those of the table grape farming land-use option. In 2017, a net revenue loss of approximately -ZAR3.3 million, -ZAR3.9 million and -ZAR4.6 million was incurred for scenarios 2, 3 and 4 respectively. In the year 2021, a net revenue loss of -ZAR2.3 million, -ZAR2.7 million and -ZAR3.2 million was incurred for Scenarios 2, 3 and 4 respectively. Thereafter, positive net revenue values were realised until the end of the model simulation (i.e. 2030), with a maximum net revenue value of ZAR32.3 million being realised from 2027 onward for Scenario 4, of ZAR32.5 million from 2028 onward for Scenario 3, and ZAR 33.2 from 2029 onward for Scenario 2.

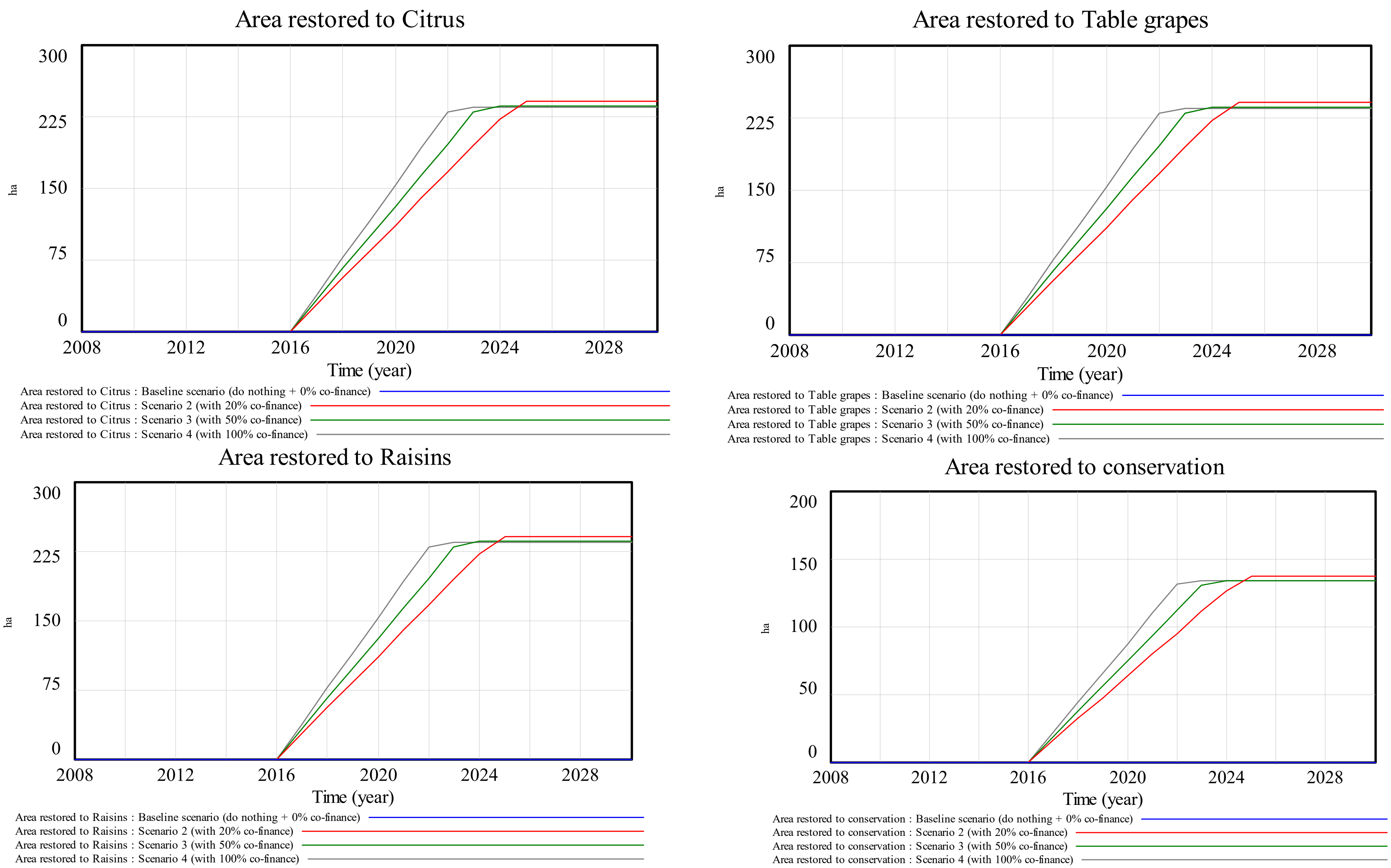

Figure 3: Dynamic behaviour over time for the area restored to natural vegetation (conservation)

Source: Own analysis

Net revenue from citrus land-use option

The results of the PROLAND model also show negative net revenue values for the citrus land-use option for 2017 to 2021. The growth trend is similar to that experienced in the table grape and raisins land-use options. In 2017, a net revenue loss of -ZAR5.2 million was incurred in Scenario 2, -ZAR6.1 million in Scenario 3 and -ZAR7.1 million in Scenario 4, while in 2021 it was approximately -ZAR6.5 million in Scenario 2, -ZAR7.7 million in Scenario 3 and -ZAR9 million in Scenario 4. Thereafter, the net revenue values became positive for the rest of the simulation period, with a maximum value of ZAR112.2 million being reached from 2029 onward for Scenario 4, of ZAR112.5 million for Scenario 3 from 2030 onward, and ZAR113.4 for Scenario 2 from 2030 onward.

4.3.2 Social benefits

Economic value of water saved due to clearing *Prosopis* spp.

The results of the PROLAND model show an increasing and decreasing pattern over time for the economic value of water savings due to *Prosopis* spp. clearance, from the initial simulation (i.e. 2008) until 2016 based on the historical clearing efforts by the DEA: NRM through its Working for Water programme. From 2017 onward (after co-finance starts), the economic value of water saved is constant right through until the end of the simulation period, amounting to approximately ZAR229 640 for the baseline scenario. Scenario 2 remains constant at approximately ZAR267 467 until 2023, and then drops to ZAR177 226 in 2024. Thereafter, the value becomes zero until the end of the simulation (i.e. 2030). For Scenario 3, the economic value for water saved also becomes constant at ZAR314 871 until 2022, with a corresponding drop in 2023 to ZAR59 506, and thereafter the value becomes zero until the end of the model simulation. Lastly, for Scenario 4, the economic value for water saved due to clearing *Prosopis* spp. also becomes constant at ZAR368 979 per annum until the year 2021, dropping to ZAR43 247 in 2022, and then the value becomes zero until the end of the model simulation. The value becomes zero due to all *Prosopis* spp. having been cleared from the invaded land.

Economic value of carbon sequestered and stored due to *Prosopis* spp. re-growth

The results of the PROLAND model show that the economic value of carbon sequestered and stored due to re-invasion by *Prosopis* spp. amounts to between approximately ZAR90 887 and ZAR95 914 for all the scenarios between 2008 and 2014. Thereafter, the value stays closely within that range for the baseline scenario until the end of the simulation period, with the exception of 2015 and 2025, when there is very little re-invasion by *Prosopis* spp. For Scenarios 2 and 3, the value drops to ZAR6 590 in 2017 and ZAR2 401 in 2016. Thereafter, the value becomes zero until the end of the simulation (i.e. 2030) due to very little or no invasion by *Prosopis* spp. As for Scenario 4, the value becomes zero from the year 2015 onward until the end of the model simulation.

4.3.3 Private costs

Total production costs for the table grape land-use option

The results of the PROLAND model simulation show a positive linear growth pattern for the production costs incurred in the table grape land-use option for the scenarios (with the exception of the baseline scenario, which remain zero for the entire simulation period), and this gradually levels off and becomes constant until the end of the simulation once the possible maximum restoration area is reached. These total annual production costs consist of the sum total of all direct and non-direct variable costs and the total fixed and overhead costs. In the year 2017, the initial production costs incurred amounted to approximately ZAR6.9 million, ZAR8.1 million and ZAR9.5 million for scenarios 2, 3 and 4 respectively. Thereafter, the total annual production costs levelled off at approximately ZAR58.1 million in 2023 onward until the simulation end (i.e. 2030) for Scenario 4, at ZAR58.6 million from 2024 onward for Scenario 3, and at ZAR59.7 million from 2025 onward for Scenario 2, as the maximum possible restoration area is achieved.

Total production costs for the raisins land-use option

The total annual production costs for the raisins land-use option also follow a positive linear growth trend over time until a maximum threshold is reached when all the possible restoration area has been achieved. Thereafter, the annual production costs become constant until the end of the simulation period. The initial production costs for 2017 amounted to approximately ZAR3.3 million for Scenario 2, ZAR3.9 million for Scenario 3 and ZAR4.6 million for Scenario 4, while they were zero for the baseline scenario throughout the whole simulation period due to the "do nothing" assumption. The annual production costs reached a climax in 2023, amounting to approximately ZAR28.1 million, ZAR28.2 million and ZAR28.9 million for scenarios 4, 3 and 2 respectively. These values then remained constant until the end of the model simulation, as all the possible maximum restoration area had been fully restored to raisins.

Total production costs for the citrus land-use option

The PROLAND model simulation also shows the same growth trend over time for the annual production costs as mentioned for the table grape and raisins land-use options for Scenarios 2, 3 and 4, while the baseline scenario values are also zero as in the aforementioned two land-use options. In 2017, the initial annual production costs incurred amounted to approximately ZAR5.2 million, ZAR6.1 million and ZAR7.2 million for scenarios 2, 3 and 4 respectively. From 2023, 2024 and 2025, the annual production costs reach a maximum and become constant until the end of the simulation for scenarios 4, 3 and 2 respectively, and amount to approximately ZAR43.9 million for Scenario 4, ZAR44 million for Scenario 3 and ZAR45.1 million for Scenario 2.

Total establishment costs for all the agricultural land-use options

The results of the PROLAND model show that the total annual establishment cost for all agricultural land-use options was constant over time from the year 2016 to 2024 for Scenario 2, 2016 to 2023 for Scenario 3 and 2016 to 2022 for Scenario 4. This amounted to approximately ZAR33.1 million, ZAR39 million and ZAR45.7 million, remaining constant until 2021, 2022 and 2023 for scenarios 2, 3 and 4 respectively. Thereafter, the annual establishment costs dropped to approximately ZAR5.4 million, ZAR7.4 million and ZAR21.9 million in 2022, 2023 and 2024 for scenarios 4, 3 and 2 respectively. As from the following year onward until the end of the simulation, the annual establishment costs dropped to zero for scenarios 2, 3 and 4 due to the maximum possible restoration area being achieved. As for the baseline scenario, no annual establishment costs were incurred due to the absence of restoration to active agricultural land uses.

Total *Prosopis* spp. clearing costs

The results of the PROLAND model show the total clearing costs incurred by the DEA: NRM through its Working for Water programme for 2008 (i.e. initial time) to 2015, based on the historical budget for all scenarios, with the value being identical since the co-finance option only starts from 2016 onward. In the initial simulation period (i.e. 2008), the total historical clearing cost amounted to ZAR804 135 for all scenarios and to ZAR716 054 in the year 2015 for all the scenarios. Thereafter, the total annual clearing costs become constant, amounting to approximately ZAR859 265, ZAR1.1

million and ZAR1.4 million until the year 2024, 2023 and 2022 for scenarios 2, 3 and 4 respectively. Afterwards, the annual clearing costs become zero, as all *Prosopis* spp. would have been cleared with the augmentation of the DEA: NRM budget by the private land users. However, for the baseline scenario, the total annual clearing costs remain constant at ZAR716 054 from 2016 onward, due to the absence of the co-finance option and the continuity of the business-as-usual case.

4.3.4 Social costs

Net economic value of carbon sequestered, stored and removed

The annual net economic value of carbon sequestered, stored and removed emanating from the PROLAND model simulation from 2008 to 2015 is based on the historic clearing efforts by the DEA: NRM through its Working for Water programme for all the scenarios. In 2008, the initial total economic value for net carbon sequestered, stored and removed amounted to ZAR613 726 for all the scenarios, and in the year 2015 it was ZAR637 444 for all the scenarios. Thereafter, the value reached a maximum of approximately ZAR742 447 for Scenario 2, remaining constant until 2023; ZAR874 033 for Scenario 3, remaining constant until 2022; and ZAR1 million for Scenario 4, remaining constant until 2021. Afterwards, the net economic value for the carbon sequestered, stored and removed dropped to approximately ZAR120 046 for Scenario 4, ZAR165 180 for Scenario 3 and ZAR491 952 for Scenario 2 in 2022, 2023 and 2024 respectively, becoming zero thereafter when all *Prosopis* spp. had been cleared off and the land had been put under active land use (until the end of the model simulation in 2030). As for the baseline scenario, the economic value for the net carbon sequestered declined slightly from the year 2016 onward, amounting to approximately ZAR570 000 as a result of the absence of the co-finance option assumption, which leads to more clearing interventions.

4.4 Feasibility analysis of clearing *Prosopis* spp. and the active use of the land

4.4.1 Cumulative net present value (NPV)

The results of the PROLAND model show a positive cumulative NPV for Scenarios 2, 3 and 4, amounting to approximately ZAR28.3 million, ZAR64.1 million and ZAR91.8 million respectively at the end of the simulation period (i.e. 2030). As for the baseline scenario, the cumulative NPV is negative, amounting to approximately -ZAR11.6 million at the end of the simulation period. The dynamic behaviour over time for the cumulative NPV is illustrated in Figure 4.

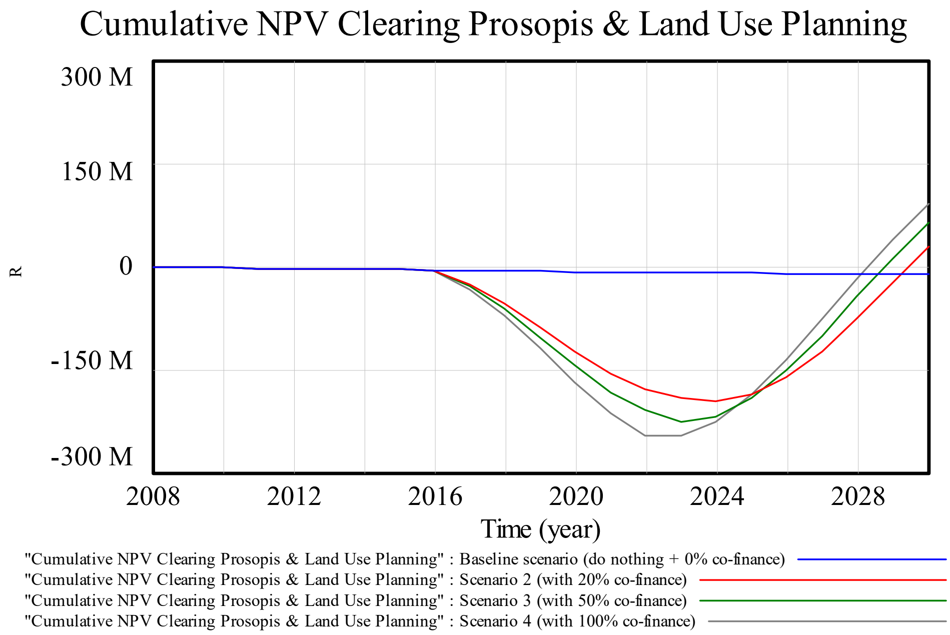

Figure 4: The dynamic behaviour over time of the cumulative NPV for clearing *Prosopis* spp. and restoring the cleared area into active land-use options
Source: Own analysis

4.4.2 Sensitivity analysis

In order to see how sensitive the modelled system was to changes in policies, we tested how the cumulative NPV responded in four situations. We assumed that all the land cleared of *Prosopis* spp. would be restored i) 100% to the natural vegetation (called conservation in the model) with no land being converted to agricultural land-use options, ii) 100% to the table grape land-use option, iii) 100% to the raisins land-use option and iv) 100% to the citrus land-use option. Having undertaken the aforementioned, only the cumulative NPV for the citrus land-use option was positive, amounting to approximately ZAR314.8 million, ZAR397 million and ZAR468.5 million for scenarios 2, 3 and 4 respectively. For the baseline scenario, however, the cumulative NPV was negative at the end of the simulation period, at approximately -ZAR12 million. As for the all the other land-use options, the cumulative NPV was negative for all the scenarios, with approximately -ZAR11.6 million, -ZAR12.9 million, -ZAR14.7 million and -ZAR16.7 million being produced for the baseline scenario and scenarios 2, 3 and 4 respectively by the end of the model simulation for the natural vegetation (i.e. conservation) land-use option. In addition, for the raisins land-use option, the cumulative NPV at the end of the model simulation amounted to approximately -ZAR11.6 million, -ZAR80.3 million, -ZAR62.3 million and -ZAR47.2 million for the baseline scenario and scenarios 2, 3 and 4 respectively. Lastly, for the table grape land-use option, the cumulative NPV at the end of the model simulation added up to approximately -ZAR11.6 million for the baseline scenario, -ZAR93 million for Scenario 2, -ZAR65 million for Scenario 3 and -ZAR41.4 million for Scenario 4.

5. Discussion and conclusion

We constructed a system dynamics model (viz. the PROLAND model), consisting of 23 simulation periods (running from 2008 until 2030) and 10 sub-models, to assess the role of sustainable land-use planning (through different active land-use options) as a strategy to deal with the invasion by *Prosopis* spp. within the study sites under investigation. Cao *et al*. (2012) mention that land-use optimisation emanating from land-use planning is a challenge marred by its high complexity due to the components under investigation being non-linear in nature. As a result, the system dynamics modelling approach was selected because of its wide application in non-linear problems characterised by high complexity

(Sterman 2000; Ford 2009; Crookes 2012; Crookes *et al*. 2013; Nkambule 2015; Crookes & Blignaut 2016; Morokong *et al*. 2016; Mudavanhu *et al*. 2016; Vundla *et al*. 2016).

In the light of the above, it is important to take note of the following:

1. We used the current state (i.e. DEA: NRM) budget for clearing *Prosopis* spp. in the study sites through the Working for Water programme as our baseline.
2. Only four scenarios were tested in this study, namely a baseline scenario (i.e. the do-nothing case + 0% co-finance), a scenario with a co-finance option of 20% (Scenario 2), one with a co-finance option of 50% (Scenario 3) and finally a scenario with a co-finance option of 100% (Scenario 4), using a conservative assumption that clearing continues at a constant rate according to the state budget for 2015.
3. The *Prosopis* spp. clearance activities are based on conservative estimates derived as a function of the effect of person days on hectares cleared and the proportion of *Prosopis* spp., which is much lower than the historical data on hectares cleared.
4. All models are wrong by definition; however, some are useful.

Given the aforementioned, it is clear that the amount being invested by the government through its control programmes is not enough to win the battle against *Prosopis* spp. as is evident from the results of the baseline scenario (no private co-finance and restoration to active land-use options) (see Figure 2). As a result, the efforts by the government are potentially in vain – something that is also called a classic “fixes that fail” archetype within the system dynamics literature (see Maani & Cavana 2007). Given the pressures among various sectors and social spheres for tax payers’ money, the Department of Environmental Affairs should consider options to augment its current clearing budget for clearing *Prosopis* spp. and convert the cleared land to active land uses if it is to win the battle of invasion by *Prosopis* spp. within the sites under investigation. The results produced by the PROLAND model show that, with increased funding (20% co-finance, 50% co-finance and 100% co-finance), *Prosopis* spp. clearing efforts yield promising prospects, as is evident from the downward trend in the area invaded by *Prosopis* spp. over the simulation period, which gradually becomes zero by 2023, 2024 and 2025 for scenarios 4, 3 and 2 respectively (see Figure 2). However, if the government continues with the business-as-usual case (the baseline scenario), the area under *Prosopis* spp. invasion will remain significantly high, as shown by the growth trend over time in the results of the baseline scenario (see Figure 2).

The cumulative NPV (using a discount rate of 6%) for scenarios 2, 3 and 4 were negative from the initial simulation period (i.e. 2008) up to 2028 (scenarios 3 and 4) and up to 2029 (Scenario 2). Thereafter, the cumulative NPV became positive, meaning that the integrated payback period (considering both society-wide externalities and private benefits and costs) of clearing *Prosopis* spp. and converting the cleared land to active land-use options was 21 years (for scenarios 3 and 4) and 22 years (for Scenario 2), given the model assumptions and scenarios considered for the purposes of this study. As for the baseline scenario, the cumulative NPV remained negative throughout the entire simulation period owing to the absence of restoration to active land uses and the co-finance assumption. Overall, at the end of the simulation period (i.e. 2030), the cumulative NPV amounted to -ZAR11.6 million for the baseline scenario, ZAR28.3 million for Scenario 2, ZAR64.1 million for Scenario 3 and ZAR91.8 million for Scenario 4. The conventional approach in cost-benefit analyses is that alternatives yielding a positive NPV are economically sound and preferable, while those with a negative NPV are the opposite and, therefore, undesirable. And so, only scenarios 2, 3 and 4 are desirable, while the baseline scenario is undesirable. Moreover, Scenario 4 should be given priority as the best possible alternative, since it yields the highest cumulative NPV, followed by Scenario 3 and lastly Scenario 2. The baseline scenario should be avoided at all costs by the relevant decision makers, such as the state and private land users to mention a few.

Having conducted a sensitivity analysis, the results of the PROLAND model show that the modelled scenarios are highly sensitive to changes in policy assumptions. Having changed the original policy assumption of apportioning the cleared area equally on a pro rata basis to the active land-use options, as explained in Section 4.4.2, only the citrus land-use option yielded a positive cumulative NPV value, while the other land-use options yielded negative cumulative NPV values (see Section 4.4.2) for all scenarios considered. As a result, and in line with the highest best-use principle, only two options are favourable, namely i) that of apportioning all the cleared land to active land-use options equally on a pro rata basis and ii) that of apportioning 100% of the cleared land to the citrus land-use option. Between the two, apportioning 100% of all the cleared land to citrus is the most desirable land use (with a cumulative NPV value amounting to approximately ZAR314.8 million in Scenario 2, ZAR397 million in Scenario 3 and ZAR468.5 million in Scenario 4), and therefore is the highest best-use option in this case. The former option (i.e. option (i)) has a cumulative NPV value adding up to approximately ZAR28.3 million for Scenario 2, ZAR64.1 million for Scenario 3 and ZAR91.8 million for Scenario 4. In the baseline scenario, no restoration to active land-use options occurs due to the "do nothing" assumption, and hence the cumulative NPV value is negative for both the aforementioned highest best-use land options.

The results arising from this study should not be considered as a "one size fits all" approach. The same analysis should be tested at other sites invaded by *Prosopis* spp. and by other IAPs to see whether or not similar findings can be produced. It is also important to note that the decision on what happens to the land after clearing lies in the hands of the decision makers (particularly the state and private land users (i.e. farmers) in our case) and, as such, this study serves as guideline for alternatives that can be explored, and as an outline of prospective behaviour over time emanating from these alternatives. Despite the two highest best land-use options presented here, other options different from those considered in this study should be explored to see how the modelled system responds and behaves over time. In conclusion, the empirical findings emanating from this study can serve as a guideline to inform land-use policy makers to come up with optimal land-use allocations from an integrated perspective that does not only look at the private costs and benefits, but also at the society-wide externality costs and benefits. As such, this study serves as one of the pioneering investigations to conduct such an analysis in South Africa in South Africa.

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