



# Investing in natural capital and national security: A comparative review of restoration projects in South Africa



Douglas J. Crookes<sup>a,\*</sup>, James N. Blignaut<sup>a,b</sup>

<sup>a</sup> School of Public Leadership, Stellenbosch University, Stellenbosch, South Africa

<sup>b</sup> South African Environmental Observation Network (SAEON), Pretoria, South Africa

## ARTICLE INFO

### Keywords:

Environmental science  
National security  
Ecological restoration  
Benefits and costs  
System dynamics  
Opportunity cost of degradation

## ABSTRACT

Does restoration pay? We seek to answer this question by reviewing the benefits and costs of 37 economic values derived from five groups of actual restoration-related case studies in South Africa at various scales. The mean opportunity costs of not restoring are the following (a negative value implies an economic loss to society): i) local level single species studies concerned with clearing invasive alien plants (mean = -\$27.24/ha/yr, sd = +/-22.93; n = 5); ii) local level multiple species studies concerned with clearing invasive alien plants (mean = -\$289/ha/yr, sd = +/-550.6; n = 14); iii) national level studies concerned with clearing invasive alien plants (mean = -\$40.2/ha/yr, sd = +/-17.2; n = 3); iv) non-clearing related restoration (mean = -\$52/ha/yr, sd = +/-154.2; n = 10); and v) agricultural land rehabilitation (mean = -\$428.1/ha/yr, sd = +/-352.7; n = 5). When these annual values are capitalised (i.e. discounted into perpetuity) to reflect the temporal impact of the foregone benefits of restoration, the losses amount to between 16 and 50 times greater than the annual values. Capitalisation of these values is an important step towards an asset-based approach in the management, restoration and conservation of natural capital. It is a step towards viewing the investment in restoration not merely as an expenditure item to be minimised, but as a truly worthwhile investment in the future wellbeing of both people and the planet – an investment in the national security of the country. More work, however, is required to transfer this value onto the balance sheets of companies in order to entice the private sector to invest more as well as to convert the implicit societal benefits of restoration to explicit company-wide value enhancement opportunities.

## 1. Introduction

While the need for the restoration of degraded natural capital at all scales can be argued conceptually, does it make economic sense to do so? (We define “economic” as being inclusive of financial and non-financial, direct and indirect costs and benefits.) If restoration does not make economic sense from this viewpoint, the project and the country is better-off without it. However, if it does make economic sense, then the opportunity cost of not restoring is negative – that is, the country is worse-off by not restoring – where opportunity cost refers to the next best alternative not opted for, or the forgone value. In this case, if a country embarks on restoration, it opts to use (or to forgo) financial capital (money) to invest in natural capital. If the benefit of such an investment exceeds the costs, then the opportunity cost is negative (note: a negative cost is a benefit). We use this simple but effective opportunity cost decision-rule to try and answer the question of whether the restoration of degraded natural capital truly pays from a national security perspective

by analysing and synthesising 37 site-specific case studies throughout South Africa, drawing on 20 years of research pertaining to the economics of restoration.

We seek to address this question with respect to the economic rationale for restoration since the degradation of natural capital is a major problem with respect to both biodiversity and conservation-related matters in many developing countries (Barbier and Hochard, 2016). Moreover, such degradation also impacts heavily on the wellbeing of people and contributes towards people becoming increasingly asset-deprived and poor (Shackleton et al., 2001; Blaikie and Brookfield, 2015). This is important since the rural poor are proportionally more reliant on natural capital for their livelihoods, which is also true in South Africa (Damania et al., 2005; Shackleton et al., 2007; Wright et al., 2016). This is a matter of grave concern since the ecosystem services on which many depend are comparable to the returns, or the flows, emanating from a capital endowment. In this case, the endowment (natural capital) is being liquidated, substantially reducing the flows (the ecosystem

\* Corresponding author.

E-mail address: [d.crookes@hotmail.com](mailto:d.crookes@hotmail.com) (D.J. Crookes).

<https://doi.org/10.1016/j.heliyon.2019.e01765>

Received 15 October 2018; Received in revised form 14 December 2018; Accepted 15 May 2019

2405-8440/© 2019 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

services) both in terms of quality and quantity. This reduction in the flow of ecosystem services impoverish those who depend on them in that i) the capability of the land is being reduced and thus the productive capacity to support income flows and livelihoods is also reduced, ii) it reduces the stream of future ecosystem services that can be expected, iii) it increases the vulnerability of those depending on the natural capital due to the reduced resilience of the system, and iv) it increases the cost of living and adaptation – hampering the ability to reinvest in the development and restoration of degraded systems, and is thus a vicious cycle. The severity of the loss is exacerbated over time by the combined pressures of population growth and increased per capita consumption, as well as by climate change which, in turn, exert further pressure on biodiversity and on ongoing efforts to conserve natural capital.

Land degradation is especially acute in the communal rangelands in South Africa (Hoffman and Todd, 2000; Scholes and Biggs, 2004; Wessels et al., 2007; Palmer and Bennett, 2013), as well as on commercial agricultural land where land is intensively and unsustainably used (Blignaut et al., 2015). Furthermore, degraded natural vegetation is also at greater risk of encroachment by invasive alien plants (IAPs) (Mack et al., 2000; Bai et al., 2008) negatively affecting biodiversity and the productive capability of the land. There is also the risk, by definition, of IAPs spreading to other areas (Richardson and Van Wilgen, 2004; Vilà et al., 2011; Van Wilgen and Le Maitre, 2013; Van Wilgen and Richardson, 2014). IAPs, among others, adversely affect water provisioning, which is critical in a semi-arid country (Le Maitre et al., 2016). Degradation of natural capital also adversely affects tourism, agricultural productivity, and social health and wellbeing (Aronson et al., 2006a). By contrast, healthy ecosystems support a higher level of local biodiversity (Kerley et al., 2003) and support human wellbeing in general (De Groot et al., 2010). Therefore restoration is necessary for achieving sustainability – it is the only intervention that augments natural capital, inclusive of biodiversity, and can relieve some of the immense pressure on natural capital due to anthropogenic action. In the process, such restoration will not only enhance the delivery of ensuing ecosystem goods and services, but it will also instil a paradigm of care and the careful management of natural capital – something that will have long-lasting impacts on the management of natural capital in future. Furthermore, restoration creates job opportunities, which is crucial in a developing country context (Gaertner et al., 2012; Kumar 2017).

Because of the strong link between the degradation of natural capital and socioeconomic development in Africa (Aronson et al., 2010a), restoration at a local level is of the utmost importance. Failing that, degradation becomes a national concern because of the consequences of degradation-induced impoverishment as mentioned above. This then leads to, among others, the increase in the prevalence of environmental refugees and conflicts (WBGU, 2008). We therefore believe that it is time to move beyond focussing on ad hoc local restoration projects or case studies that, by and large, view restoration only as an expense, the playground of either the rich and/or of academic concern. Rather, the restoration in natural capital should be viewed as an investment in an asset – natural capital – and hence a sustainable future (Aronson et al., 2010b). The restoration of natural capital is thus of strategic, national, concern as it has the potential to stop or reverse land degradation, preventing the liquidation of natural capital and sustaining and enhancing all forms of life, and allowing them to prosper. Restoration is therefore not merely an expenditure/cost item that has to be minimised, and that is all too often subject to cost-cutting processes. It is truly an investment in an asset and thus the future welfare of people and the planet (see also Mudavanhu et al., 2017a; Blignaut, 2019). It is therefore fundamental to consider restoration within the context of national security, where such is defined as:

*... the protection of a nation from attack or other danger by holding adequate armed forces and guarding state secrets. The term national security encompasses within it economic security, monetary security, energy*

*security, environmental security, military security, political security and security of energy and natural resources.*

(USLegal.com n.d.).

Within this strategic context restoration builds resilience, reduces the risk degradation poses to people and their vulnerabilities, and it increases natural and environmental resource security. Failing to restore reduces such security at both local and national level.

Despite these arguments in favour of restoration, the question remains, does it pay economically? De Groot et al. (2013) and Elmqvist et al. (2015) have indicated that restoration pays at a global level, but does it pay at site and country levels? This study seeks to address this gap. This gap simultaneously also reflects another aspect, and that is the gap between the biophysical need for restoration and the societal value and/or appreciation of restoration in financial and economic terms. Implicit in the question whether restoration pays, supported by local, national-level evidence, is the question whether the societal need of and value for restoration, as reflected in the economic value thereof, matches the biophysical need thereof. In doing this gap analysis we begin by describing the database, followed by a description of the two methods used to assess the net benefits of restoration, namely i) the opportunity cost approach, and ii) a portfolio mapping exercise to determine whether restoration activities are worthwhile when compared to the risk that the restoration might fail. Finally, results from the assessment are given and the implications for restoration considered.

## 2. Material and methods

In this section we discuss both the database of studies that was developed, as well as the means by which it was analysed.

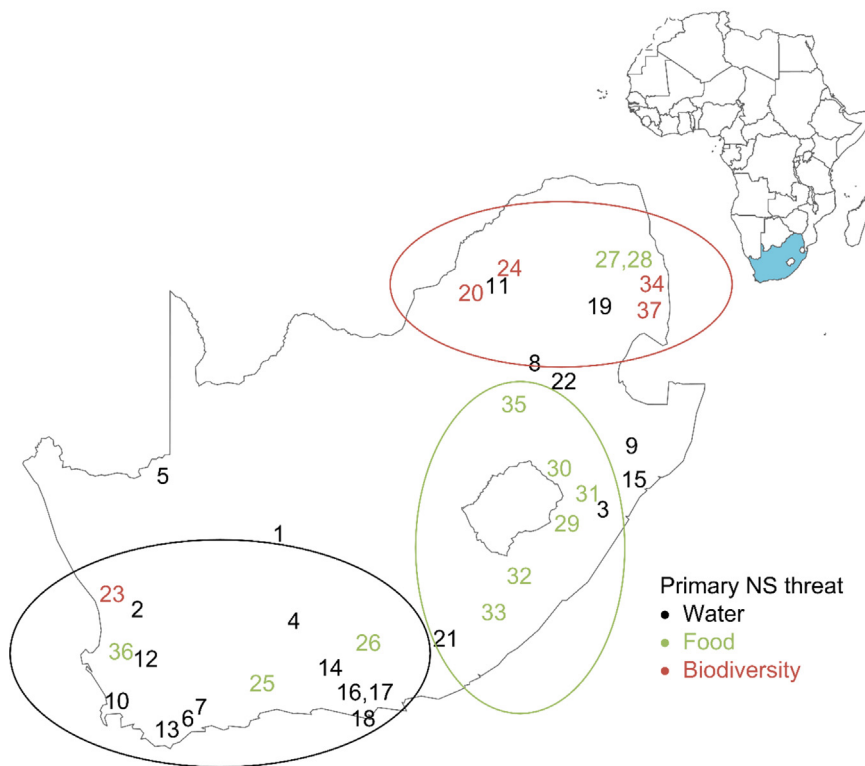
### 2.1. Description of the database

A database of 37 site-specific opportunity cost values (based on 26 papers published in peer-reviewed literature) was compiled from studies analysing the benefits and costs of actual restoration projects in South Africa (see Fig. 1). The criteria for selecting these 37 site-specific values are as follows: they are selected from restoration studies in South Africa that have i) been published in peer-reviewed literature in journals that are indexed by the South African government<sup>1</sup>, ii) detailed the benefits and the costs of restoration, and iii) followed a consistent and comparable research method (see Appendix 1 for further particulars). The studies vary both in terms of temporal and spatial distribution as well as restoration method to avoid site selection bias (Reid et al., 2018). It should be noted that the selected studies took into consideration the site-specific spatial and temporal complexities as well as the fact that the benefits of restoration often occurs only after a lag, and then incrementally so. Therefore, we do not have to account for these site-specific characteristics here as we use the results from those studies that reflect the impacts of, among others, the aforementioned complexities.

The case studies can be divided into five groups, namely:

1. local level single species studies concerned with clearing IAPs (SS; n = 5 – see Table 1);
2. local level multiple species studies concerned with clearing IAPs (MS; n = 14 – see Table 2);
3. national level studies concerned with clearing IAPs (Nat; n = 3 – see Table 3);
4. non-clearing related restoration, i.e. the restoration of wetlands, gullies, and the reseeded and replanting of denuded areas to reduce sediment loss (NCR; n = 10 – see Table 4); and

<sup>1</sup> <https://www.sun.ac.za/english/research-innovation/Research-Development/outputs-accredited-journals/accredited-journals>.



**Fig. 1.** Location of 37 study sites where the opportunity cost of not restoring natural capital has been analysed. Casual observation shows that the majority of water security threats assessed (by case study) are in the south-west of South Africa, the majority of food security threats assessed (by case study) are in the eastern part of the country, and the majority of biodiversity threats to national security assessed (by case study) are in the north-west of the country. This corresponds to the bio-physical realities of the country. Note: Numbers of the sites refer to the numbers as per Tables 1, 2, 3, 4, and 5; NS = National security. Numbers repeated refer to multiple study sites. Primary NS threat is allocated based on the paper content. If the paper is on IAPs, then water is the primary NS threat; if the paper is on communal or commercial grazing or crops, then food is the primary NS threat; and if the paper is on threats to wildlife or bush encroachment, then biodiversity is the primary NS threat.

## 5. restoration related to agricultural and game/wildlife management systems (CAS; n = 5 – see Table 5).

The costs and benefits of restoration are mirrored by the costs and benefits of non-restoration. To avoid double counting though, we offset the costs of restoration against the benefits of restoration. Examples of such costs and benefits include the following:

- Costs of restoration:
  - The financial costs, inclusive of both capital as well as management expenses over time, of restoration and the cost of ongoing sustainable land use management.
  - The foregone value of the elevated rates of carbon dioxide sequestration of non-native plants that have been cleared.
- A non-exhaustive and conservative list of the benefits of restoration:
  - The value of the water loss avoided by the clearing of IAPs.
  - The value of the siltation of dams avoided by reducing soil erosion.
  - The value of the loss of soil carbon avoided by reducing soil erosion.
  - The value of the degraded pasture avoided through improved management and the adjustment of stocking rates.
  - The value of the loss of livestock and crop production capabilities avoided through improved management and the adjustment of stocking rates.
  - The value of the loss of tourism avoided.
  - The value of the (potential) revenues from *inter alia* the sales of value-added products (VAPs) from clearing IAPs and its use as, for example, a bioenergy source.

## 2.2. Data analysis

We analyse the data from the database in two ways. First, we reflect on the estimate of the opportunity cost of not restoring natural capital. Second, we assess the merit of the various restoration projects by using

portfolio mapping.

There are two values associated with the opportunity costs assessment of either restoring or not restoring natural capital:

### 1. The annual flow of benefits foregone by not restoring, (\$/ha/yr):

This is calculated based on the net present value (NPV) from restoration, annualised and divided by the area of the study. They are thus unit, or marginal, NPVs as they provide the NPV of restoring an additional hectare per year. The formula for calculating the annualised values is as follows:

$$\text{Annual flow} = \frac{rNPV}{1 - (1 + r)^{-n}}$$

Where  $r$  is the discount rate,  $NPV$  is the net present value of the study in question, and  $n$  is the number of periods. These values were obtained from the individual studies that were considered. All historic values have been standardised to 2017-values using the Consumer Price Index (CPI). For the agricultural system, annual values of the net present values (2017 \$/ha/yr), after taking into the consideration the costs of restoration and the economic benefits associated with improved productivity of these systems, are calculated in order to ensure comparability between the studies. An exchange rate of R13.21:\$ has been used throughout, which was the spot exchange rate on 2017/07/04 (Grain SA, 2017).

### 2. The opportunity cost of the capital loss from not restoring:

Blignaut and Aronson (2008) and Mudavanhu et al. (2017a) argue that the value of natural capital is the services derived from it discounted into perpetuity. We therefore use the annualised opportunity cost estimates and discount that into perpetuity, i.e. divide the NPV by a discount rate without taking time into consideration, in order to estimate the capital loss through not restoring. Two discount rates are used: a low 2

percent discount rate to reflect the scarcity value of diminishing ecosystems at the same (approximate) rate as the annual population growth of adults (StatsSA, 2018), and a 6 percent discount rate, being the long-run (private) opportunity cost of money (Du Preez et al., 2013; Department of Energy, 2016). The lower the discount rate, the higher the capital value, or the more the future is appreciated. Under conditions of a high discount rate the short-term is considered more important than the long-term. Given that natural capital is considered (i.e. assets that have shown the capability to last for a long time), low, or even negative, discount rates might be appropriate (Blignaut and Aronson, 2008). We argue that it is better to use such negative discounting in the context of time-specific analysis and not when discounting into perpetuity – and thus only used positive values. This approach is in line with the recent acknowledgment by the accounting profession that natural capital is an asset; they broadened their definition of what constitutes an asset to also include natural capital (IASB, 2018 par 4:3; Blignaut, 2019).

Second, we assess the merits of a restoration project relative to its associated potential risks of failure. Portfolio mapping is a well-established technique for ranking projects based on the probability of success of the projects compared with their perceived rewards (Cooper et al., 1997). Projects are usually classified into one of the following four quadrants:

- Oysters: These are long-shot projects with high expected payoffs but also high risk.
- Pearls: These are potential star products: projects with a low risk that are expected to yield a high reward.
- Bread and butter: These are small, simple projects with a high likelihood of success but low reward.
- White elephants: These are projects that consume resources and are unlikely to produce commercial value.

Traditionally, with respect to portfolio mapping, projects are plotted in a bubble diagram with the bubble size representing the amount of resources committed to or available for the project. For our database, the probability of success was not available so, following Crookes et al. (2013), the coefficient of variation (CV) of the opportunity cost values is used as a proxy for the probability of restoration success. It is assumed that the higher the CV the lower the probability of success given the increase in uncertainty and thus risk. Also, we do not have the resources available, so the area invaded/restored is used as a proxy. It is assumed that the larger the restored area is, the greater the resources required. In the next section, the results are presented.

### 3. Results

#### 3.1. Annual forgone or gained opportunity cost as a result of restoration

The opportunity cost of not clearing single species (SS) at a local level ranges between -\$2.38/ha/year and -\$63.43/ha/year (2017 values) (Table 1). In all cases considered the opportunity cost of not restoring is negative implying that non-restoration translates into a societal loss. The net present value of the discounted financial costs and associated cost items are therefore less than the benefits of restoration.

The opportunity cost of not clearing multiple species (MS) at a local level has a much wider range of values than SS. Here the opportunity cost ranges from \$112.63/ha/year (a net benefit to society if restoration is not done) to -\$1 552.80/ha/year (a net cost to society if restoration is not done) (see Table 2). The societal benefits of not restoring exceeds the costs (i.e. a positive opportunity cost) under such situations where the direct financial cost of restoration exceed the potential estimated (or included) benefits of such restoration. Only a single study indicated such a positive opportunity cost (Mudavanhu et al., 2016). In contrast, Stafford and Blignaut (2017) concluded, for the same site but after including the value of the potential sale of electricity from the use of IAPs, a small negative opportunity cost. As a general observation the opportunity cost

values in this instance are much higher than that of the other categories. These results underscore the importance of context-specific (local) studies.

While only three studies focussed on the opportunity cost of not restoring at a national level (Nat), the values fall within a narrow and low range. The values range from -\$20.40/ha/year to -\$51.71/ha/year at 2017 prices (see Table 3).

Non-clearing restoration (NCR) involves active restoration by means other than clearing IAPs, including bush thinning and the restoration of gullies. Values range from \$298/ha/year (a net benefit to society if restoration is not done) to -\$280.77/ha/year (a net cost to society if restoration is not done) (see Table 4). The study site with the positive opportunity cost, Namaqualand (Crookes et al., 2013), refers to a statutory dune mining rehabilitation operation post mining. The restoration is expensive due to the severity of the land transformation and the prescribed mine rehabilitation protocol in an extremely dry area (see Pauw et al., 2018 for more details). For the most part though, the net benefits of NCR are generally low mainly due to the higher financial costs of restoration in this instance. The only exception is the Ntabelanga site (Bester et al., 2018), which estimates the opportunity cost of not restoring as it relates to a major dam silting more rapidly than would otherwise have been the case had gully restoration occurred, thereby reducing the economic lifespan of the dam. The high cost is due to the incomes of multiple downstream users, which are dependent on the dam's water supply being affected by this siltation.

The opportunity costs of not pursuing conservation agricultural systems (CAS) ranges between -\$141.54/ha/year and -\$994.10/ha/year (Table 5).

#### 3.2. Opportunity costs of not restoring natural capital over time

The net present values indicated in Tables 1, 2, 3, 4, and 5 are marginal values, that is, they indicate the net present value of restoring one additional hectare per year. The average annual opportunity cost values of the different restoration systems range between -\$27.24/ha/year and -\$428.1/ha/year (2017 values, see Table 6). The negative average annual flow values are indicative of the annual society-wide (inclusive of financial cost) loss in economic value. These flow values can be used to estimate the loss in the value of the natural capital asset. That is since the value of any asset, including financial and manufactured capital, can be estimated as the net present value of the sum of the flows over the lifetime of the asset. The potential yet realistic lifetime of natural capital is infinite given its history. Discounting the annual flow value therefore into perpetuity gives the true economic value of the natural capital loss through not restoring. Capital values are between 16 and 50 times greater than the annual values ranging from -\$454/ha to -\$21 400/ha. This is indicative of what is at stake and the high opportunity costs of not restoring, yet it is likely a very conservative value as it does not take cognisance of all ecosystem services (Turpie et al., 2017).

When classifying the costs by type of land degradation (see Table 6), wildlife resources' degradation is the highest. Caution, however, should be exercised in interpreting the value since the sample size is low and focusses on high value charismatic species (rhinos and elephants) only. Cropland degradation was also high but is also based on only a limited number of studies. The costs of IAP degradation averages -\$274/ha/year (2017 values), with a capital value ranging between -\$4 573/ha and -\$13 719/ha (Table 6). The value includes both single species and multiple species assessments. Communal and commercial grazing loss contributes the next greatest loss, at -\$132.8/ha/year and -\$167/ha/year, respectively. As expected, commercial grazing loss is higher than communal grazing loss as the value of agricultural production is higher. The difference is relatively small due to the addition of other ecosystem services as well (provisioning, regulating and cultural). Bush encroachment, based on our assessment of restoration studies, contributes the next lowest to land degradation, averaging -\$12.3/ha/year (2017 values). Strip mining, on the other hand, produces a benefit from not restoring of

**Table 1**

Local level studies with respect to the clearing of single species of invasive alien plants.

| Number <sup>1</sup> | Authors & year of publication | Type of degradation (species) <sup>2</sup> | Restoration method <sup>3</sup> | Where?                                   | Annualised opportunity cost 2017 \$/ha/yr <sup>4</sup> |
|---------------------|-------------------------------|--------------------------------------------|---------------------------------|------------------------------------------|--------------------------------------------------------|
| 1                   | Vundla et al. (2016b)         | IAPs ( <i>Prosopis</i> spp)                | 3                               | Northern Cape                            | -2.38                                                  |
| 2                   | Mudavanhu et al. (2017b)      | IAPs ( <i>Acacia Saligna</i> )             | 2, 3                            | Citrusdal, De Hoop, Berg river catchment | -15.04                                                 |
| 3                   | Vundla et al. (2017a)         | IAPs ( <i>Egeria densa</i> )               | 2, 3                            | Midmar Dam                               | -24.04                                                 |
| 4                   | Crookes et al. (2013)         | IAPs ( <i>Prosopis</i> spp)                | 2, 3                            | Beaufort West                            | -31.30                                                 |
| 5                   | Mudavanhu et al. (2017c)      | IAPs ( <i>Prosopis</i> spp)                | 2, 3                            | Northern Cape                            | -63.43                                                 |

<sup>1</sup> See Fig. 1 for the location of the studies linked to corresponding numbers.<sup>2</sup> Type of degradation: IAPs = Invasive alien plants.<sup>3</sup> Restoration method: 2 = mechanical clearing; 3 = chemical treatment.<sup>4</sup> Studies ranked from the lowest to the highest opportunity cost.**Table 2**

Local level studies with respect to the clearing of multiple species of invasive alien plants.

| Number <sup>1</sup> | Authors & year of publication | Restoration method <sup>2</sup> | Where?                             | Annualised opportunity cost 2017 \$/ha/yr <sup>3</sup> |
|---------------------|-------------------------------|---------------------------------|------------------------------------|--------------------------------------------------------|
| 6                   | Mudavanhu et al. (2016)       | 2,                              | De Hoop, Agulhas                   | 112.63                                                 |
| 7                   | Stafford and Blignaut (2017)  | 2, 4                            | Agulhas                            | -1.32                                                  |
| 8                   | Morokong et al. (2016)        | 1                               | Olifants Limpopo                   | -8.94                                                  |
| 9                   | Nkambule et al. (2017)        | 1, 2, 3                         | Northern Zululand                  | -9.98                                                  |
| 10                  | Crookes (2018)                | 1, 4, 5                         | Berg, Breede WMA                   | -11.44                                                 |
| 11                  | Morokong et al. (2017)        | 1                               | Mokolo river catchment, Limpopo    | -21.15                                                 |
| 12                  | Mudavanhu et al. (2017d)      | 2, 3                            | Berg river catchment, Western Cape | -39.85                                                 |
| 13                  | Crookes et al. (2013)         | 1, 2, 3                         | Agulhas                            | -59.32                                                 |
| 14                  | Vundla et al. (2016a)         | 2, 3                            | Kouga-Kromme                       | -68.93                                                 |
| 15                  | Vundla et al. (2017b)         | 2, 3                            | Zululand, KwaZulu-Natal            | -90.23                                                 |
| 16                  | Crookes et al. (2013)         | 2, 3                            | Kromme – no agriculture            | -248.94                                                |
| 17                  | Crookes et al. (2013)         | 2, 3                            | Kromme                             | -515.80                                                |
| 18                  | Mugido et al. (2014)          | 2, 3                            | Port Elizabeth                     | -1,529.29                                              |
| 19                  | Crookes et al. (2013)         | 2, 3                            | Sand river                         | -1,552.80                                              |

<sup>1</sup> See Fig. 1 for the location of the studies linked to corresponding numbers.<sup>2</sup> Restoration method: 1 = biological control; 2 = mechanical clearing; 3 = chemical treatment; 4 = physical clearing; 5 = construction of desalination plant.<sup>3</sup> Studies ranked from the lowest to the highest opportunity cost.**Table 3**

National level studies of the opportunity cost of not restoring natural capital.

| Number <sup>1</sup> | Authors & year of publication | Type of degradation (species) <sup>2</sup> | Restoration method <sup>3</sup> | Where?         | Annualised opportunity cost 2017 \$/ha/yr <sup>4</sup> |
|---------------------|-------------------------------|--------------------------------------------|---------------------------------|----------------|--------------------------------------------------------|
| 20                  | Stafford et al. (2017)        | BE                                         | 6                               | National scale | -\$ 20.40                                              |
| 21                  | De Wit et al. (2001)          | IAPs ( <i>Acacia mearnsii</i> )            | 1, 4                            | National scale | -\$ 48.43                                              |
| 22                  | Stafford et al. (2017)        | IAPs (MS)                                  | 2, 4                            | National scale | -\$ 51.71                                              |

<sup>1</sup> See Fig. 1 for the location of the studies linked to corresponding numbers.<sup>2</sup> Type of degradation: BE = bush encroachment; IAPs = invasive alien plants; MS = multiple species.<sup>3</sup> Restoration method: 1 = biological control; 2 = mechanical clearing; 4 = physical clearing; 6 = bush thinning.<sup>4</sup> Studies ranked from the lowest to the highest opportunity cost.

\$298/ha/year. The benefits from strip mining is, obviously, the returns from selling the minerals.

In terms of national security threat, food security had the lowest opportunity cost if not restored, at -\$164.3/ha/yr (2017 values). This is partly due to lower values from communal (subsistence) farming systems (Table 6). Biodiversity was next, with an opportunity cost of -\$174.6/ha/yr. Although values are high for wildlife, lower values for bush encroachment and the mining of marginal lands in the west of the country reduced this opportunity cost. The opportunity cost of not restoring water is the highest national security threat currently in South Africa in terms of economic values, at -\$274/ha/yr (see Table 6 and Fig. 2). This is not surprising given the aridity of the country and emphasises the ongoing importance of IAP clearing interventions among a suite of other water supply and demand management initiatives that are required in order to make South Africa water secure.

### 3.3. Portfolio mapping

Next, a portfolio mapping exercise was undertaken to assess which restoration systems should receive the highest priority. If a risk averse strategy is pursued, the pearl projects are most desirable, followed by the bread and butter projects, then the oyster projects, and finally the white elephants. The portfolio mapping exercise (Fig. 3) indicates that there are neither 'white elephant' nor 'bread and butter' projects. Most restoration projects are 'pearl' projects. Those are projects with a high probability of success (measured herein as a relatively low coefficient of variance of the opportunity cost values among the studies considered) and high payoff in terms of the economic value of benefits derived. These included: 1) single species (SS) studies; 2) national level (Nat) studies; 3) food security restoration projects (food); 4) conservation agriculture (CAS) restoration projects. The rest were classified as 'oyster' projects, meaning that the uncertainties and thus the risks are higher than among the others and the payoff more uncertain compared to the 'pearl' projects. These include: 1) non-clearing restoration (NCR); 2) biodiversity restoration projects ('biodiversity'); 3) multiple species invasive alien plant (MS) studies; 4) water restoration projects ('water'). This implies that each of these projects should be assessed on their own merit. MS and SS projects require relatively much lower resources compared to CAS system projects. National level and single species restoration projects therefore provide the

**Table 4**

Local level studies of non-clearing restoration (NCR).

| Number <sup>1</sup> | Authors & year of publication | Type of degradation <sup>2</sup> | Restoration method <sup>3</sup> | Where?                       | Annualised opportunity cost (2017 \$/ha/yr <sup>4</sup> ) |
|---------------------|-------------------------------|----------------------------------|---------------------------------|------------------------------|-----------------------------------------------------------|
| 23                  | Crookes et al. (2013)         | Mining                           | 7, 8, 9                         | Namaqualand                  | 298.00                                                    |
| 24                  | Crookes et al. (2013)         | BE                               | 6                               | Lephalale                    | -4.21                                                     |
| 25                  | Crookes et al. (2013)         | C'ercial gr                      | 8, 9, 10                        | Oudtshoorn                   | -5.76                                                     |
| 26                  | Mander et al. (2010)          | C'ercial & c'unal gr             | 9                               | Baviaanskloof & Tsitsikamma  | -20.23                                                    |
| 27                  | Blignaut and Loxton (2007)    | C'unal gr                        | 9                               | Bushbuckridge                | -25.49                                                    |
| 28                  | Blignaut and Moolman (2006)   | C'unal gr                        | 9                               | Bushbuckridge                | -25.67                                                    |
| 29                  | Blignaut et al. (2010)        | C'unal gr                        | 9                               | Upper Umzimvubu, Drakensberg | -123.70                                                   |
| 30                  | Blignaut et al. (2010)        | C'unal gr                        | 8, 11                           | Upper uThukela, Drakensberg  | -135.44                                                   |
| 31                  | Crookes et al. (2013)         | C'unal gr                        | 11                              | Drakensberg                  | -196.93                                                   |
| 32                  | Bester et al. (2018)          | C'unal gr                        | 11, 12                          | Ntabelanga                   | -280.77                                                   |

<sup>1</sup> See Fig. 1 for the location of the studies linked to corresponding numbers.<sup>2</sup> Type of degradation: Mining = strip mining; BE = Bush encroachment; C'ercial gr = Commercial grazing land degradation; C'unal gr = Communal grazing land degradation.<sup>3</sup> Restoration method: 6 = bush thinning; 7 = topsoil replacement, 8 = seeding, 9 = planting; 10 = Soil ripping, 11 = Gully restoration; 12 = construction of dam.<sup>4</sup> Studies ranked from the lowest to the highest opportunity cost.**Table 5**

Studies of the opportunity cost of not pursuing conservation agricultural system.

| Number <sup>1</sup> | Authors & year of publication | Type of degradation <sup>2</sup>  | Restoration method <sup>3</sup> | Where?               | Annualised opportunity cost 2017 \$/ha/yr <sup>4</sup> |
|---------------------|-------------------------------|-----------------------------------|---------------------------------|----------------------|--------------------------------------------------------|
| 33                  | Blignaut et al. (2017)        | C'unal gr (beef)                  | 13                              | Nationwide           | -\$ 141.54                                             |
| 34                  | Blignaut et al. (2008)        | Wildlife (elephants) <sup>5</sup> | 14, 16                          | Kruger National Park | -\$ 152.43                                             |
| 35                  | Blignaut et al. (2017)        | C'ercial gr (beef)                | 13                              | Nationwide           | -\$ 328.17                                             |
| 36                  | Crookes et al. (2017)         | LEF Crops (wheat)                 | 15                              | Western Cape         | -\$ 524.06                                             |
| 37                  | Crookes and Blignaut (2015)   | Wildlife (rhinos) <sup>5</sup>    | 14, 16                          | Nationwide           | -\$ 994.10                                             |

<sup>1</sup> See Fig. 1 for the location of the studies linked to corresponding numbers.<sup>2</sup> Type of degradation: LEF = Langgewens experimental farm; C'ercial gr = Commercial grazing land degradation; C'unal gr = Communal grazing land degradation; Wildlife = Wildlife resources degradation; Crops = cropland degradation;<sup>3</sup> Restoration method: 13 = Improved pasture management; 14 = Improve capacity of land to support wildlife; 15 = Conversion to conservation (no-till) farming; 16 = Prevention of poaching.<sup>4</sup> Studies ranked from the lowest to the highest opportunity cost.<sup>5</sup> Only tourism and life sales included in wildlife values (no consumptive values).

greatest opportunity as far as water security is concerned. Conservation agriculture also provides a high probability of success in terms of food security; however, it requires more financial support from donors, government, or major commercial entities. Potential high payoffs may lure private investors to invest, though. Biodiversity restoration has positive payoffs, but it is the most uncertain in terms of probability of success. Usually, the private sector is not willing to undertake high risk investments. The potential payoff would need to be high. However, consumptive benefits, although yielding higher returns, may not be sustainable (Crookes and Blignaut, 2015). This suggests that government will continue to play an important role in biodiversity promotion.

NPVs are the benefits of restoration which are the opposite of the opportunity cost of not restoring (which were negative). The bottom right quadrant is the most desirable outcome.

#### 4. Discussion

Internationally, only a few multi-site reviews have been conducted of the opportunity cost of not restoring natural capital across a range restoration methods and degradation types. This fact is further supported by Bullock et al. (2011) who indicate that cost data on restoration studies are very scarce and stated that TEEB (The Economics of the Environment and Biodiversity project) reviewed 20 000 restoration studies and only found 96 that contained any usable cost data. De Groot et al. (2013) and Elmqvist et al. (2015) contributed to this body of literature. While these studies refer to actual cases with respect to the cost of restoration, they use the estimates of the international values of ecosystem services as per Costanza et al. (1997) and De Groot et al. (2012) as a proxy for the benefits of restoration. This study, and supporting database, use site-specific benefits and costs of restoration that seek to honour the

complexities of both the biophysical realities as well as difficulties associated with restoration. It thus contributes greatly to this pool of studies. Since it is based on a multiple number (37) of actual restoration projects, with actual data with respect to both the benefits and the costs of restoration, not only is the credibility of the outcome greatly enhanced, but it was also possible to consider inter-site nuances.

Before reflecting on the results, a brief note with respect to future research and the reporting on the data is warranted. While most restoration-related research papers focus on the technical detail of the restoration itself, researchers are encouraged to also include both economic and financial data. Careful consideration should be given to whether the reported cost data is capital cost, or whether it includes operational cost. Is the reported cost annualised cost or total project cost? Does the cost include any in-kind contribution or not? Is the cost reported on in terms of average cost or marginal cost? By being specific about the reported cost, future assessments of this kind seeking to synthesise the results as well as the database with respect to our understanding of the cost of restoration will be greatly aided. Likewise, future research reporting on restoration would do well if it can report on the benefits thereof. How were the benefits calculated, over what time period, and which benefits were included? Such reporting will demonstrate the impact of restoration across a wide-spectrum of study sites.

With the information at our disposal from the 37 study sites reported on here we can conclude that restoration does pay, but it does not pay equally in all cases. This is indicative of how difficult it is to incorporate all benefits all the time, as even the studies considered do not include all the benefits. It does, however, support the fact that site-specific assessments are important. These site-specific characteristics thus necessitates local-level assessments of both the costs and the benefits in a coherent and replicable manner.

**Table 6**  
Costs of not restoring different systems.

|                                                   | n  | Average annual<br>opportunity cost of<br>not restoring (2017<br>\$/ha/yr) <sup>1,2</sup> | Capitalised<br>opportunity cost<br>of not restoring<br><br>2017 \$/ha @ 6%<br>d.r. <sup>3</sup> | Capitalised<br>opportunity cost<br>of not restoring<br><br>2017 \$/ha @ 2%<br>d.r. <sup>3</sup> |
|---------------------------------------------------|----|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|
| <i>Classification by restoration scale/type</i>   |    |                                                                                          |                                                                                                 |                                                                                                 |
| SS                                                | 5  | -27.24 (+/-22.93)                                                                        | -454.0                                                                                          | -1,361.9                                                                                        |
| Nat                                               | 3  | -40.2 (+/-17.2)                                                                          | -669.7                                                                                          | -2,009.0                                                                                        |
| NCR                                               | 10 | -52.0 (+/-154.5)                                                                         | -867.0                                                                                          | -2,600.9                                                                                        |
| MS                                                | 14 | -289.0 (+/-550.6)                                                                        | -4,815.9                                                                                        | -14,447.7                                                                                       |
| CAS                                               | 5  | -428.1 (+/-352.7)                                                                        | -7,134.4                                                                                        | -21,403.1                                                                                       |
| <i>Classification by type of degradation</i>      |    |                                                                                          |                                                                                                 |                                                                                                 |
| Mining                                            | 1  | 298.0 (na)                                                                               | 4,966.6                                                                                         | 14,899.9                                                                                        |
| BE                                                | 2  | -12.3 (+/- 11.4)                                                                         | -205.0                                                                                          | -615.1                                                                                          |
| Other gr                                          | 1  | -20.2 (na)                                                                               | -337.1                                                                                          | -1,011.3                                                                                        |
| C'unal gr                                         | 7  | -132.8 (+/- 90.5)                                                                        | -2,213.2                                                                                        | -6,639.5                                                                                        |
| C'ercial gr                                       | 2  | -167.0 (+/- 228.0)                                                                       | -2,782.8                                                                                        | -8,348.3                                                                                        |
| IAPs                                              | 21 | -274.4 (+/- 460.8)                                                                       | -4,572.8                                                                                        | -13,718.5                                                                                       |
| Crops                                             | 1  | -524.1 (na)                                                                              | -8,734.4                                                                                        | -26,203.2                                                                                       |
| Wildlife                                          | 2  | -573.3 (+/- 595.1)                                                                       | -9,554.4                                                                                        | -28,663.3                                                                                       |
| <i>Classification by National Security threat</i> |    |                                                                                          |                                                                                                 |                                                                                                 |
| Food                                              | 11 | -164.3 (+/- 160.7)                                                                       | -2,739.0                                                                                        | -8,217.1                                                                                        |
| Biodiversity                                      | 5  | -174.6 (+/- 486.9)                                                                       | -2,910.5                                                                                        | -8,731.4                                                                                        |
| Water                                             | 21 | -274.4 (+/- 460.8)                                                                       | -4,572.8                                                                                        | -13,718.5                                                                                       |

Nat = National level studies; NCR = non-clearing restoration; SS = single species clearing; MS = multiple species clearing; CAS = conservation agricultural system;

Type of degradation: BE = bush encroachment; IAPs = invasive alien plants; C'nal gr = communal grazing land degradation; C'ercial gr = commercial grazing land degradation; Wildlife = wildlife loss; Crop = Cropland degradation; Mining = strip mining degradation.

<sup>1</sup> Studies ranked from the lowest to the highest opportunity cost.

<sup>2</sup> Standard deviation provided in parenthesis.

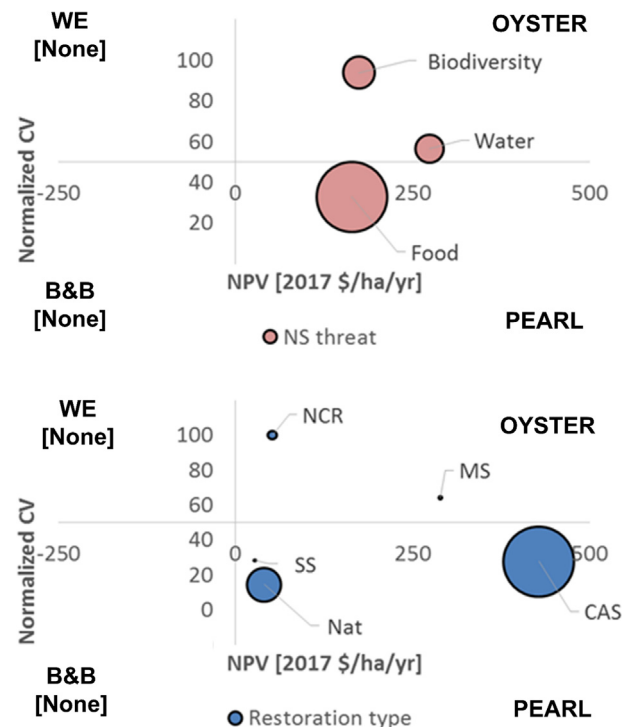
<sup>3</sup> d.r. = discount rate.

Some of the highest returns to restoration, however, is related to the potential for private benefits. This opens the opportunity for private sector investment in the restoration of natural capital (see also Blignaut, 2019 in this regard). What this implies, and given the fact that restoration is an investment in the future, is that mechanisms should be developed whereby such restoration, and the contribution it is making towards national security, is acknowledged by allowing companies to account for such on their balance sheets. It can be argued that an investment in restoration, like any other investment in either manufactured or financial

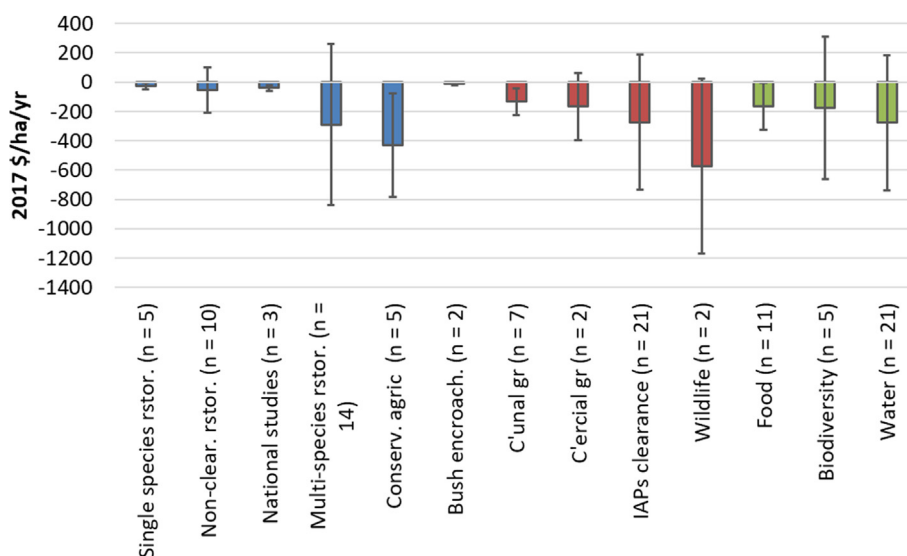
capital, enhances a company's asset holding – more so given the recently adopted definition of the International Accounting Standards Board (IASB) of what defines an asset, namely:

*An asset is a present economic resource controlled by the entity as a result of past events (IASB, 2018: par 4.3).*

We used a definition of an asset compatible with the above in analysing 37 economic values from restoration-related case studies in South Africa covering 20 years and found that, except for two, all studies indicate a negative opportunity cost if restoration is not implemented.



**Fig. 3.** Results of the portfolio map of restoration systems. Notes: The size of the bubble indicates area restored, a proxy for resources committed. WE = White elephant projects; B&B = bread and butter projects; CV = coefficient of variation; NS = national security.



**Fig. 2.** The annualised opportunity cost of not restoring natural capital in 2017 US\$/ha/year. Note: The sample of 37 case studies with respect to the opportunity cost is divided in terms of restoration type and scale (blue bars), the type of degradation (red bars) and the national security threat that the restoration addresses (green bars). The mean values are provided in the bars and the error bars are standard deviations. The number of observations (n) are given together with the legend. Only data with more than one observation are shown. The highest annualised opportunity costs of not restoring are from conservation agriculture studies (CAS), and wildlife loss. Water is the greatest national security threat in terms of opportunity cost. Most data are available for invasive alien plants (IAPs, n = 21), followed by food security studies (n = 11).

With respect to the two exceptions, the results of one were overturned by another study when broadening the calculation to include more benefit streams, and the other being statutory restoration following mining. It can be argued that if the value of the resource rents of the minerals, an ecosystem provisioning service, is included in the mining case, then the benefits of restoration far exceeds the costs. This review's results, conservative as they are since they do not include all benefits of restoration, indicates strongly that the country will be worse-off if restoration is not conducted. Some of the unquantified benefits include, for example, the benefit of employment and raising environmental awareness through restoration projects are not included. These unquantified benefits are extremely important given that direct employment in the agricultural and tourism sectors alone comprise over 10% of total employment in South Africa (DAFF, 2017). Restoration and related activities contribute to this and, moreover, to food security. In addition, the benefits of relieving the pressures on conservation efforts are also not included. If these and other benefits of restoration are included, the opportunity cost of not restoring will just be higher. This is important since it demonstrates to policy-makers and funding agencies the importance of restoration, helping to increase the success of future restoration projects by promoting greater return on investment (Hughes et al., 2018). It also demonstrates that restoration enhances the provision of ecosystem goods and services (Rey Benayas et al., 2009) and the benefits of assessing multiple ecosystem services impacted by restoration (Bullock et al., 2011), and highlights the need for further restoration work, particularly at a local level. Finally, this review serves to enhance the evidence base for restoration, which Gellie et al. (2018) argue is crucial to meet restoration targets such as the Bonn Challenge, highlighting the importance of restoration for environmental policy. The Bonn Challenge is a global initiative aimed at restoring 350 million hectares of the world's deforested and degraded land by 2030, initiated by the German government and IUCN. Thus far (December 2018), 168 million hectares have been pledged (see the Bonn challenge website: <http://www.bonnchallenge.org/for details>).

This aspect is eloquently captured by Daly (in Aronson et al., 2006b:1), when stating:

*More and more, the complementary factor in short supply (limiting factor) is remaining natural capital, not manmade capital as it used to be. For example, populations of fish, not fishing boats, limit fish catch worldwide. Economic logic says to invest in the limiting factor. That logic has not changed, but the identity of the limiting factor has.*

Restoration, the investment in the limiting factor to economic development (natural capital), is furthermore a fundamental recognition that our current development trajectory, and the underlying societal value system of extract, produce, use and discard, is not sustainable. The restoration of natural capital is the acknowledgement that our current economic conduct requires restoration, and urgently so. Moreover, this is a recognition that the biophysical need for restoration is matched by the societal value thereof. This necessitates further investment in restoration.

## 5. Conclusion

Within the context of population increase and the pressures exerted by climate change, restoration can no longer be considered as merely a cost item on an expenditure account of a company or government, but truly as an indispensable investment in the future of both people and the planet. This is since, due to increasing scarcity, the preservation and augmentation of natural capital has become an issue of national security. Restoration is a means to protect, and guard, the nation from the dangers related to not having enough environmental and natural resources – which invariably poses a threat to the wellbeing and safety of the nation. Overwhelmingly the evidence suggest that restoration does pay economically. More work, however, is required to transfer this value onto the balance sheets of companies to entice the private sector to invest

more and to convert the implicit societal benefits of restoration to explicit company-wide value enhancement opportunities.

## Declarations

### Author contribution statement

Douglas J. Crookes, James N. Blignaut: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

### Funding statement

This work was supported by the NRM: DEA (South Africa).

### Competing interest statement

The authors declare no conflict of interest.

### Additional information

Supplementary content related to this article has been published online at <https://doi.org/10.1016/j.heliyon.2019.e01765>.

## References

- Aronson, J., Clewell, A.F., Blignaut, J.N., Milton, S.J., 2006a. Ecological restoration: a new frontier for nature conservation and economics. *J. Nat. Conserv.* 14 (3–4), 135–139.
- Aronson, J., Blignaut, J., Milton, J., Clewell, A., 2006b. Natural capital: the limiting factor. *Ecol. Eng.* 28, 1–5.
- Aronson, J., Blignaut, J.N., Milton, S.J., Le Maitre, D., Esler, K.J., Limouzin, A., Fontaine, C., De Wit, M.P., Mugido, W., Prinsloo, P., Van der Elst, L., Lederer, N., 2010a. Are socioeconomic benefits of restoration adequately quantified? A meta-analysis of recent papers (2000–2008) in Restoration Ecology and 12 other scientific journals. *Restor. Ecol.* 18, 143–154.
- Aronson, J., Blignaut, J., de Groot, R., Clewell, A., Lowry II, P., Woodworth, P., Renison, D., Tongway, D., Cowling, R., Fontaine, C., de Wit, M., Farley, J., Levy, S., Milton, S., Rangel, O., Debrincat, B., Birkinshaw, C., 2010b. The road to sustainability must bridge three great divides. *Ann. N. Y. Acad. Sci.* 1185, 225–236.
- Bai, Z.G., Dent, D.L., Olsson, L., Schaepman, M.E., 2008. Proxy global assessment of land degradation. *Soil Use Manag.* 24 (3), 223–234.
- Barbier, E.B., Hochard, J.P., 2016. Does land degradation increase poverty in developing countries? *PLoS One* 11 (5), e0152973.
- Bester, R., Blignaut, J.N., Crookes, D., 2018. The Impact of Human Behaviour and Restoration on the Economic Lifespan of the Proposed Ntabelanga and Lalení Dams, South Africa. *Water Resources Economics*. In press.
- Blaikie, P., Brookfield, H. (Eds.), 2015. *Land Degradation and Society*. Routledge, Oxford.
- Blignaut, J.N., Aronson, J., 2008. Getting serious about maintaining biodiversity. *Conserv. Lett.* 1 (1), 12–17.
- Blignaut, J., Moolman, C., 2006. Quantifying the potential of restored natural capital to alleviate poverty and help conserve nature: a case study from South Africa. *J. Nat. Conserv.* 14 (3–4), 237–248.
- Blignaut, J.N., Loxton, C.E., 2007. An approach to quantify the economic value of restoring natural capital: a case from South Africa. In: Aronson, J., Milton, S.J., Blignaut, J.N. (Eds.), *Restoring Natural Capital: Business, Science, and Practice*. Island Press, Washington D.C.
- Blignaut, J., De Wit, M.P., Barnes, J., 2008. The economic value of elephants. In: Scholes, B., Mennell, K. (Eds.), *Elephant Management. A Scientific Assessment for South Africa*. WITS University Press, Johannesburg.
- Blignaut, J., Mander, M., Schulze, R., Horan, M., Dickens, C., Pringle, C., Mavundla, K., Mahlangu, I., Wilson, A., McKenzie, M., McKean, S., 2010. Restoring and managing natural capital towards fostering economic development: evidence from the Drakensberg, South Africa. *Ecol. Econ.* 69 (6), 1313–1323.
- Blignaut, J., Knot, J., Smith, H., Nkambule, N., Crookes, D., Saki, A., Drimie, S., Midgley, S., De Wit, M., Von Loeper, W.J., Strauss, J., 2015. Promoting and Advancing the Uptake of Sustainable, Regenerative, Conservation Agricultural Practices in South Africa with a Specific Focus on Dryland maize and Extensive Beef Production. Key Findings and Recommendations. Asset Research. ASSET Research, Pretoria booklet nr 2.
- Blignaut, J., Crookes, D., Saki, A., 2017. The demand for ecosystem services of different calf production systems in South Africa. *Afr. J. Agric. Resour. Econ.* 12 (2), 158–173.
- Blignaut, J.N., 2019. Making investment in natural capital count. *Ecosyst. Serv.* 37, 100927.
- Bullock, J.M., Aronson, J., Newton, A.C., Pywell, R.F., Rey-Benayas, J.M., 2011. Restoration of ecosystem services and biodiversity: conflicts and opportunities. *Trends Ecol. Evol.* 26 (10), 541–549.

- Cooper, R.G., Edgett, S.J., Kleinschmidt, E.J., 1997. Portfolio management in new product development: lessons from the leaders—II. *Res. Technol. Manag.* 40 (6), 43–52.
- Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., et al., 1997. The value of the world's ecosystem services and natural capital. *Nature* 387, 253–259.
- Crookes, D.J., Blignaut, J.N., De Wit, M.P., Esler, K.J., Le Maitre, D.C., Milton, S.J., Mitchell, S.A., Cloete, J., De Abreu, P., Fourie (nee Vlok), H., Gull, K., Marx, D., Mugido, W., Ndhlovu, T., Nowell, M., Pauw, M., Rebelo, A., 2013. System dynamic modelling to assess economic viability and risk trade-offs for ecological restoration in South Africa. *J. Environ. Manag.* 120, 138–147.
- Crookes, D.J., Blignaut, J.N., 2015. Debunking the myth that a legal trade will solve the rhino horn crisis: a system dynamics model for market demand. *J. Nat. Conserv.* 28, 11–18.
- Crookes, D.J., Strauss, J., Blignaut, J.N., 2017. The effect of rainfall variability on sustainable wheat production under no-till farming systems in the Swartland region, South Africa. *Afr. J. Agric. Resour. Econ.* 12 (10), 62–84.
- Crookes, D.J., 2018. Does the construction of a desalination plant necessarily imply that water tariffs will increase? A system dynamics analysis. *Water Resour. Econ.* 21, 29–39.
- DAFF (Department of Agriculture, Forestry and Fisheries), 2017. Abstract of Agricultural Statistics 2016. Government printer, Pretoria.
- Damania, R., Milner-Gulland, E.J., Crookes, D.J., 2005. A bioeconomic analysis of bushmeat hunting. *Proc. R. Soc. Lond. B Biol. Sci.* 272 (1560), 259–266.
- De Groot, R.S., Fisher, B., Christie, M., Aronson, J., Braat, L., Haines-Young, R., Gowdy, J., Maltby, E., Neuville, A., Polasky, S., Portela, R., Ring, I., 2010. Integrating the ecological and economic dimensions in biodiversity and ecosystem service valuation. In: Kumar, P. (Ed.), *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Earthscan, London.
- De Groot, R.S., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., Ten Brink, P., Van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst. Serv.* 1, 50–61.
- De Groot, R.S., Blignaut, J.N., Van Der Ploeg, S., Aronson, J., Elmqvist, T., Farley, J., 2013. Benefits of investing in ecosystem restoration. *Conserv. Biol.* 27, 1286–1293.
- Department of Energy, 2016. *Integrated Energy Plan*. <http://www.energy.gov.za/files/IEP/2016/IEP-AnnexureB-Macroeconomic-Assumptions.pdf>. (Accessed 4 March 2019).
- De Wit, M.P., Crookes, D.J., Van Wilgen, B.W., 2001. Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion. *Biol. Invasions* 3, 167–178.
- Du Preez, M., Beukes, J., Van Dyk, E.E., 2013. A Cost-Benefit Analysis of Concentrator Photovoltaic Technology Use in South Africa: A Case Study. *ERSA working paper* 343.
- Elmqvist, T., Setälä, H., Handel, S.N., Van Der Ploeg, S., Aronson, J., Blignaut, J.N., Gomez-Baggethun, E., Nowak, D.J., Kronenberg, J., De Groot, R., 2015. Benefits of restoring ecosystem services in urban areas. *Curr. Opin. Environ. Sustain.* 14, 101–108.
- Gaertner, M., Nottebrock, H., Fourie, H., Privett, S.D.J., Richardson, D.M., 2012. Plant invasions, restoration, and economics: perspectives from South African fynbos. *Perspect. Plant Ecol. Evol. Systemat.* 14, 341–353.
- Gellie, N.J., Breed, M.F., Mortimer, P.E., Harrison, R.D., Xu, J., Lowe, A.J., 2018. Networked and embedded scientific experiments will improve restoration outcomes. *Front. Ecol. Environ.* 16 (5), 288–294.
- Grain, S.A., 2017. *Grain SA's Morning Grain Market Commentary, 2017/07/05*. Available at: [https://www.grainsa.co.za/upload/report\\_files/GSA-Morning-Grain-Market-Commentary-05-Jul-2017.pdf](https://www.grainsa.co.za/upload/report_files/GSA-Morning-Grain-Market-Commentary-05-Jul-2017.pdf). (Accessed 5 December 2018).
- Hoffman, M.T., Todd, S., 2000. A national review of land degradation in South Africa: the influence of biophysical and socio-economic factors. *J. South. Afr. Stud.* 26 (4), 743–758.
- Hughes, A.R., Grabowski, J.H., Leslie, H.M., Scyphers, S., Williams, S.L., 2018. Inclusion of biodiversity in habitat restoration policy to facilitate ecosystem recovery. *Conserv. Lett.* 11 (3), 1–8.
- International Accounting Standards Board (IASB), 2018. *Conceptual Framework for Financial Reporting*. International Accounting Standards Board, London.
- Kerley, G.L., Pressey, R.L., Cowling, R.M., Boshoff, A.F., Sims-Castley, R., 2003. Options for the conservation of large and medium-sized mammals in the Cape Floristic Region hotspot, South Africa. *Biol. Conserv.* 112 (1–2), 169–190.
- Kumar, P., 2017. Innovative tools and new metrics for inclusive green economy. *Curr. Opin. Environ. Sustain.* 24, 47–51.
- Le Maitre, D.C., Forsyth, G.G., Gush, M.B., Dziki, S., 2016. Estimates of the impacts of invasive alien plants on water flows in South Africa. *WaterSA* 42, 659–672.
- Mack, R.N., Simberloff, D., Lonsdale, W.M., Evans, H., Clout, M., Bazzaz, F.A., 2000. Biotic invasions: causes, epidemiology, global consequences, and control. *Ecol. Appl.* 10, 689–710.
- Mander, M., Blignaut, J.N., Van Niekerk, M., Cowling, R., Horan, M., Knoesen, D., Mills, A., Powell, M., Schulze, R., 2010. *Baviaanskloof-Tsitsikamma PES Feasibility: Synthesis Report*. Future Works, Everton.
- Morokong, T., Blignaut, J., Nkambule, N.P., Mudavanhu, S., Vundla, T., 2016. Clearing invasive alien plants as a cost-effective strategy for water catchment management: the case of the Olifants river catchment, South Africa. *S. Afr. J. Econ. Manag. Sci.* 19 (5), 774–787.
- Morokong, T., Nkambule, N.P., Blignaut, J.N., Vundla, T., Mudavanhu, S., 2017. Determining the potential of the extensive and intensive agricultural production to co-finance DEA's activities of clearing invasive alien plant species on private farms: the case of the Mokolo River catchment in Limpopo Province, South Africa. *Afr. J. Agric. Resour. Econ.* 12 (4), 276–288.
- Mudavanhu, S., Blignaut, J., Nkambule, N., Morokong, T., Vundla, T., 2016. A cost-benefit analysis of using Rooikrans as biomass feedstock for electricity generation: a case study of the De Hoop nature reserve, South Africa. *S. Afr. J. Econ. Manag. Sci.* 19 (5), 788–813.
- Mudavanhu, S., Blignaut, J., Stegmann, N., Barnes, G., Prinsloo, W., Tuckett, A., 2017a. The economic value of ecosystem goods and services: the case of Mogale's Gate Biodiversity Centre, South Africa. *Ecosyst. Serv.* 26, 127–136.
- Mudavanhu, S., Blignaut, J.N., Vink, N., Crookes, D., Meincken, M., Effah, B., Murima, D., Nkambule, N., 2017b. An assessment of the costs and benefits of using *Acacia Saligna* (Port Jackson) and recycled thermoplastics for the production of wood polymer composites in the Western Cape Province, South Africa. *Afr. J. Agric. Resour. Econ.* 12 (4), 322–365.
- Mudavanhu, S., Blignaut, J.N., Vink, N., Crookes, D., Nkambule, N., 2017c. An economic analysis of different land-use options to assist in the control of the invasive *Prosopis* (Mesquite) tree. *Afr. J. Agric. Resour. Econ.* 12 (4), 366–411.
- Mudavanhu, S., Nkambule, N.P., Blignaut, J., Vundla, T., Morokong, T., 2017d. A cost-benefit analysis of clearing invasive alien plants in the Berg River quaternary catchment of South Africa. *Afr. J. Agric. Resour. Econ.* 12 (4), 289–321.
- Mugido, W., Blignaut, J.N., Joubert, M., De Wit, J., Knipe, A., Jobert, S., Cobbing, B., Jansen, J., Le Maitre, D., Van der Vyfer, M., 2014. Determining the feasibility of harvesting invasive alien plant species for energy. *South Afr. J. Sci.* 110 (11/12).
- Nkambule, N.P., Blignaut, J.N., Vundla, T., Morokong, T., Mudavanhu, S., 2017. The benefits and costs of clearing invasive alien plants in northern Zululand, South Africa. *Ecosyst. Serv.* 27 (Part B), 203–223.
- Palmer, A.R., Bennett, J.E., 2013. Degradation of communal rangelands in South Africa: towards an improved understanding to inform policy. *Afr. J. Range Forage Sci.* 30 (1–2), 57–63.
- Pauw, M.J., Esler, K.J., Le Maitre, D.C., 2018. Assessing the success of experimental rehabilitation on a coastal mineral sands mine in Namaqualand. *South Africa. Afr. J. Range Forage Sci.* 35 (3–4), 363–373.
- Reid, J.L., Fagan, M.E., Zahawi, R.A., 2018. Positive site selection bias in meta-analyses comparing natural regeneration to active forest restoration. *Science advances* 4 (5), 9143.
- Rey Benayas, J.M., Newton, A.C., Diaz, A., Bullock, J.M., 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: a meta-analysis. *Science* 325 (5944), 1121–1124.
- Richardson, D.M., Van Wilgen, B.W., 2004. Invasive alien plants in South Africa: how well do we understand the ecological impacts? *South Afr. J. Sci.* 100 (1–2), 45–52.
- Scholes, R.J., Biggs, R., 2004. *Ecosystem Services in Southern Africa: A Regional Assessment. A Contribution to the Millennium Ecosystem Assessment*. CSIR, Pretoria.
- Shackleton, C.M., Shackleton, S.E., Cousins, B., 2001. The role of land-based strategies in rural livelihoods: the contribution of arable production, animal husbandry and natural resource harvesting in communal areas in South Africa. *Dev. South Afr.* 18 (5), 581–604.
- Shackleton, C.M., Shackleton, S.E., Buiten, E., Bird, N., 2007. The importance of dry woodlands and forests in rural livelihoods and poverty alleviation in South Africa. *For. Policy Econ.* 9 (5), 558–577.
- Stafford, W., Blignaut, J., 2017. Reducing landscape restoration costs: feasibility of generating electricity from invasive alien plant biomass on the Agulhas Plain, South Africa. *Ecosyst. Serv.* 27 (Part B), 224–231.
- Stafford, W., Birch, C., Etter, H., Blanchard, R., Mudavanhu, S., Angelstame, P., Blignaut, J., Ferreira, L., Marais, C., 2017. The economics of landscape restoration: benefits of controlling bush encroachment and invasive plant species in South Africa and Namibia. *Ecosyst. Serv.* 27 (Part B), 193–202.
- StatsSA, 2018. *Mid-year Population Estimates*. Statistics South Africa, Pretoria.
- Turpie, J.K., Forsythe, K.J., Knowles, A., Blignaut, J., Letley, G., 2017. Mapping and valuation of South Africa's ecosystem services: a local perspective. *Ecosys. Serv.* 27, 179–192.
- USLegal.com. (n.d.). *National Security Law and Legal Definition*. Available at: <https://definitions.uslegal.com/n/national-security/> (accessed on 30 June 2018).
- Van Wilgen, B.W., Le Maitre, D.C., 2013. *Rates of Spread in Invasive Alien Plants in South Africa*. CSIR, Stellenbosch. Unpublished CSIR Report No. CSIR/NRE/ECOS/ER/2013/0107A.
- Van Wilgen, B.W., Richardson, D.M., 2014. Challenges and trade-offs in the management of invasive alien trees. *Biol. Invasions* 16 (3), 721–734.
- Vilá, M., Espinar, J.L., Hejda, M., Hulme, P.E., Jarošík, V., Maron, J.L., Pergl, J., Schaffner, U., Sun, Y., Pyšek, P., 2011. Ecological impacts of invasive alien plants: a meta-analysis of their effects on species, communities and ecosystems. *Ecol. Lett.* 14 (7), 702–708.
- Vundla, T., Blignaut, J., Nkambule, N., Morokong, T., Mudavanhu, S., 2016a. The opportunity cost of not utilising the woody invasive alien plant species in the Kouga, Krom and Baviaans catchments in South Africa. *S. Afr. J. Econ. Manag. Sci.* 19 (5), 814–830.
- Vundla, T., Nkambule, N.P., Blignaut, J.N., Morokong, T., Mudavanhu, S., 2016b. Cost-benefit Analysis of the Restoration of *Prosopis* in the Northern Cape. ASSET Research, Pretoria.
- Vundla, T., Blignaut, J.N., Crookes, D., 2017a. Aquatic weeds: to control or not to control. The case of the Midmar Dam, KwaZulu-Natal, South Africa. *Afr. J. Agric. Resour. Econ.* 12 (4), 412–429.
- Vundla, T., Blignaut, J.N., Crookes, D., 2017b. Financing active restoration in South Africa: an evaluation of different institutional models. *Afr. J. Agric. Resour. Econ.* 12 (4), 430–453.

- WBGU (German Advisory Council on Global Change), 2008. Climate Change as a Security Risk. Earthscan, London and Sterling, VA.
- Wessels, K.J., Prince, S.D., Malherbe, J., Small, J., Frost, P.E., Van Zyl, D., 2007. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *J. Arid Environ.* 68 (2), 271–297.
- Wright, J.H., Hill, N.A., Roe, D., Rowcliffe, J.M., Kümpel, N.F., Day, M., Booker, F., Milner-Gulland, E.J., 2016. Reframing the concept of alternative livelihoods. *Conserv. Biol.* 30 (1), 7–13.