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The benefits of ecological restoration exceed its cost in South Africa: An evidence-based approach

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ABSTRACT

Ecological restoration has become a development intervention of choice at the highest levels of governance at a global level. In due recognition of the restoration of ecosystems' capability and potential to contribute to economic, ecological and social wellbeing and health, the United Nations and its partners announced the UN decade of restoration which commenced in 2021. The strategic importance of restoration at a time when resources are under serious pressure necessitates that we take stock of what the costs and the benefits of restoration are. We analysed all the known papers published in peer-reviewed journals on the costs and benefits of restoration since 1997 for South Africa to make inferences about the cost-effectiveness thereof.

The net present value (NPV) of restoration, using a discount rate of 7% over a 25-year timespan, was estimated for several ecosystems. It was found that given the wide standard deviation of the values observed, mean values have little application. We, therefore, compare the costs and the benefits of restoration according to four cohorts, or quartiles, of values. The NPV/ha for quartile 1 (benefits less costs) and quartile 3 (benefits less costs) in 2020-values are estimated as follows: Fynbos at -US$49/ha and -US$564/ha; rivers, lakes and waterbodies at US$467/ha and US$3 2964/ha; Savanna at US$2974/ha and US$23 657/ha; Grasslands at -US$457/ha and -US$806/ha; Succulent Karoo at -US$205/ha and US$362/ha; Deserts at US$90/ha and US$43/ha; and Thicket at US$2 958/ha and US$4 641/ha.

Except for the Succulent Karoo and Fynbos, the benefits of restoration likely exceed its costs, and by some considerable margin in most cases. It is thus recommended that not only more research be conducted in those cases where there are only a few estimates but also that estimates are made for a wider range of benefits. A concerted effort must be made to implement a country-wide restoration programme to the benefit of both the current and future generations.

1. Introduction

1.1. Costs and benefits of restoration: Dealing with uncertainty

Scepticism has recently been expressed concerning the ability of ecological restoration – defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Society for Ecological Restoraiton 2002) – to be successful, efficient, scalable and beneficial to society (Cooke et al., 2019; Bradbury et al., 2021). Much of the stated scepticism is economic by nature due to the uncertainties about the estimated costs and benefits of restoration. Restoration cost and benefit estimates are scarce or problematic since (i) two unique sets of calculations are required, one for costs and one for benefits, each based on different measures of valuation, delineations, functional complexities and conceptualisations of value and time, (ii) the rewards linked to the benefits and the cost burden often accrue to different members of society, or stakeholders, (iii) the benefits and costs are often reported in units that are incompatible, with the costs being financial expenses and the benefits often best described in bio-physical terms, or even intangible, (iv) the sources of data arise from a range of different restoration practitioners, researchers and beneficiaries with communication structures among them that are either weak or even non-existing due to temporal and spatial distances, (v) the timeframes over which the benefits and the costs accrue varies substantially with the

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Table 1
Summary of available databases on the benefits and costs of ecological restoration.

Databases	What does it contain	Years covered	# of studies on South Africa	Link
Aronson et al. (2010)	Restoration classification system with implications as to the economics of it	2001–2008	36 case studies	https://doi.org/10.1016/j.cosust.2012.12.003
TEEB database	Monetary value of ecosystem services	1994–2010	22 case studies	https://www.es-partnership.org/esvd/esvd-download/original-teeb-database/
ESVD database	Monetary value of ecosystem services	2003–2018	25 case studies	https://www.es-partnership.org/esvd/
Cost database	Restoration method (varied) costs	2003–2008	4 case studies	https://doi.org/10.1016/j.jenvman.2013.02.001
Crookes and Blignaut (2019)	Opportunity cost of not restoring natural capital	2001–2018	37 case studies	https://doi.org/10.1016/j.jenvman.2013.02.001
Turpie et al. (2017)	Estimates of ecosystem services for South Africa	1979–2017	Spatial datasets, census data and studies quantifying ecosystem functioning	https://doi.org/10.1016/j.ecoser.2017.07.008
Crookes et al. (2013)	Risk analysis for restoration taking into consideration restoration success, likely costs and likely benefits	2010–2012	8 case study sites	https://doi.org/10.1016/j.jenvman.2013.02.001

costs being mainly upfront while the benefits are delayed over time and dependent on various management and environmental conditions, and (vi) estimates of both the costs and the benefits are not subject to standardised reporting conventions causing differences in language use far too great for search algorithms to predict or circumnavigate (Blignaut et al., 2014).

The need for an increased and focussed effort on restoration in South Africa has never been bigger. South Africa is in the grip of wide-scale degradation despite spending more than R16 billion (US$1.1 billion) on public restoration projects over the past two decades (Von Maltitz et al., 2019). The degradation and its drivers comprise, among others: (i) a third of cultivated land moderately to very severely degraded (Lindeque & Koegelenberg, 2015); (ii) invasive alien plants infestations of 10 million ha causing annual streamflow reductions of 3% (Kotzé et al., 2010); (iii) 7.3 million ha worth of ecosystem goods and services disrupted by bush encroachment (Turpie et al., 2019); (iv) 12 ton/ha/year of topsoil lost annually with 30.5 million ha prone to severe soil erosion and 0.57 million ha riddled with dongas (Le Roux, 2011); (v) 77% of all estuarine ecosystems in degraded condition due to overfishing and declining river water quality including an estimated daily 840 million m^3 of wastewater discharged directly into estuaries (Van Niekerk et al., 2020); (vi) 18% of natural habitats have been lost to date; and (vii) 40% of terrestrial ecosystems, 57% of the rivers and 65% of wetlands are threatened by degradation with waste generation across South Africa having increased by 62% in the past decade alone (Department of Environmental Affairs, 2016).

There is an ongoing effort to quantify the costs and the benefits of restoration which speaks to the ecological mess we are in and the difficulties in providing information about the value of restoration. An increasing and ongoing production and collection of cost and benefit estimates have made several tools and databases available at a global and local scale (Table 1). However, a low number of South African case studies in these databases does not encourage the use thereof in decision making. Difficulties arise at all points in estimate supply chain, namely the production of these estimates, integrity, their collection, analysis and distribution. Particularly, the collection processes appear inefficient evident in Table 1 by the variation of case study for South Africa found across various databases.

We suggest here that the perceived shortage in the production of primary data is less problematic than imagined. This paper studies and reports on the collective transdisciplinary and unintentional effort of the South African research community to promote the allocation of resources into restoration programmes through the reporting of cost and benefit estimates for restoration. In the subsequent section we explain how, in attempting to create a more complete South African database of cost and benefit estimates, papers were collected and analysed. We discuss the results of these processes, their findings and implications for restoration decision-making and restoration cost and benefit database construction going forward.

2. Methods and materials

A thorough review of all relevant and available peer-reviewed papers pertaining to the costs and the benefits of restoration in South Africa up to the end of 2020 has been made. The process and methods of collecting, filtering and organising data comprised of three stages, namely: (i) sourcing peer-reviewed papers using a set of keywords as per Blignaut et al. (2014); (ii) stakeholder engagement to both source additional peer-reviewed papers and ground-truth the database compiled; and (iii) identifying papers suitable for the quantitative database.

Papers were added to the database based on three criteria, namely:

1. The paper had to be of a study site in South Africa or incorporating South Africa (allowing for global studies).
2. The paper had to be concerned with ecological restoration – the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (SER 2002).
3. The paper had to:
   a. elaborate on a qualitative aspect of the economics of restoration (philosophy, strategy, policy, institutional implications, etc.); and/or.
   b. quantify benefits and costs of restoration; and/or.
   c. reference quantified benefits and costs of restoration in other studies or papers; and/or.
   d. benefits and costs of restoration as well as a need to quantify these; and/or.
   e. describe how restoration benefited ecosystem health, function and/or integrity.

The papers providing quantified cost and benefit estimates would be isolated and estimates would be extracted for analysis. This data has been organized by year and by category allowing for degradation type, benefit type, cost type and unit of measurement to comment on the estimate generation processes of South Africa. This enabled a *meta*-analysis, reported on herein. All values have been standardised or converted to 2020 US dollar ($)/ha/year values using an exchange rate of $1 = R14.55 and South Africa's consumer price index where applicable and appropriate.

Inspection of data sets showed that ranked $/ha/year benefit

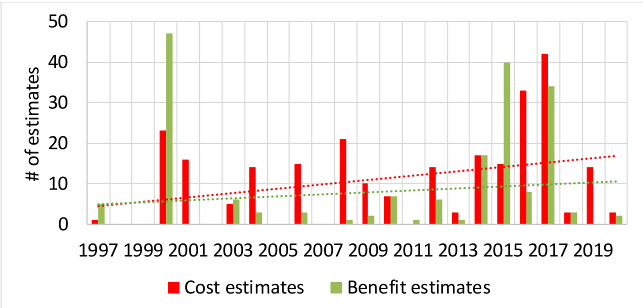

Fig. 1. The number of cost and benefit estimates over time including the respective linear trend lines indicating the general pattern and direction of change of the number of estimates produced per year between 1997 and 2020.

estimates per ecosystem type were correlated with the benefit or basket of benefits for which it was calculated. The more ecosystem services were included in an estimate the larger the estimate would be. The majority of $/ha/year cost estimates per ecosystem type were for operating costs. The removal of outliers from the benefit and cost datasets was deemed unnecessary based on the nature the data. Analysis was performed on this dataset in a manner comparable to that of De Groot et al. (2013), Blignaut et al. (2014) and Elmqvist et al. (2015).

Using these unit values we calculate estimates for quartiles 1, 2, 3, and 4 (herein denoted as Q1, Q2,Q3 and Q4). By using quartiles to analyse the data, mean values with high standard deviation values as well as obscuring data symmetry bias, are avoided. Estimates are ranked from smallest to largest and partitioned with the Q2 equal to the median entry (the middle entry) of this ranked series, Q4 reporting on the largest value and Q1 and Q3 reporting on the 25th percentile and 75th percentile of this ranked series. We estimated the NPV of the benefit of restoration per ecosystem type for 25 years. This has been done using a financial industry-relevant discount rate often used to ascertain the viability of long-term investment projects of 7% (Spiro 2010). We allow the costs of restoration projects to decline exponentially over the first five years and allow for a maintenance cost equal to 5% of the cost estimate until the end of the term. The benefits are incrementally phased in over a 5-year period so that in the first period only 20% of the estimated benefit accrues to the land, in the second year 40%, etc. until it reaches 100% of the estimated benefits where after it remains constant.

3. Results

3.1. Literature review

The database used by Crookes and Blignaut (2019) provided a starting point of 58 papers. Five keyword searches with sufficient query variation (of words "environment", "restoration", "restore", "ecological", "economic", "invasive alien plant", "South Africa", "benefit" and "cost") yielded another 32 unique papers. Keyword searches ended as subsequent searches yielded ever decreasing returns in terms of unique papers, and it became unclear under what keyword variation scientists might have published costs and benefits. Thereafter, the research team engaged with the researchers via email (94 emails in total), inviting them to review the database and contribute to it. In total, 86 relevant papers or documents were received from stakeholders, of which 77 were unique (not already included in the database). Of these 77 papers, 36 were found to contain quantified benefit and cost values. Overall, paper sourcing activities yielded 177 papers included in the database, available at https://assetresearch.org.za/media-resources/, in which restoration cost and benefits for South Africa were discussed or mentioned in the texts. In identifying papers suitable for quantitative analysis, the application of the desired criteria resulted in 76 papers where costs and benefits were estimated or reported for a South African case study published between 1997 and 2020. These 76 papers contain 256 estimates of the cost of ecological restoration and 191 estimates of the benefits thereof.

3.2. Organisation of data

In studying the combined 447 benefit and cost estimates, we can comment about their frequency over time, how they were reported and what they measured. The publication of restoration costs and benefits are increasing as is indicated by the linear trend line fitted to the data which is plotted in Fig. 1. It appears that the number of cost estimates published annually is increasing faster than the number of benefit estimates published annually (Fig. 1). This not only signals the importance of the subject matter, and the increasing interest therein, but also the fact that costs are much easier to estimate than the benefits.

Characteristics of the estimates are detailed in Table A1. The units of measure used most (112) were Rand/year, followed by net present value NPV in Rand terms (95) and Rand/ha/year (50). Most estimates, 275 in total, focussed on the impacts of invasive alien plants with changes in land cover (56) being the second largest group of papers in terms of the type of degradation. The most frequent types of cost reported were operating costs (119), management cost (35), and once-off capital cost (20). Benefit estimates were predominately for water supply (87), food provisioning (Liniger et al., 2019), and tourism and recreational services (Currie et al., 2009).

After conversions between data units, 80 benefits estimates and 176 cost estimates with unit values in the form of $/ha/year were compiled and are used for quantitative analysis. The variance for areas over which restoration occurred is large. A few studies reported for restoration sites exceeding 1 million hectares. On average benefits are estimated for restoration done over 8.2 million hectares and costs for restoration done over 313 thousand hectares.

Net present values and present values make up 135 estimates; and

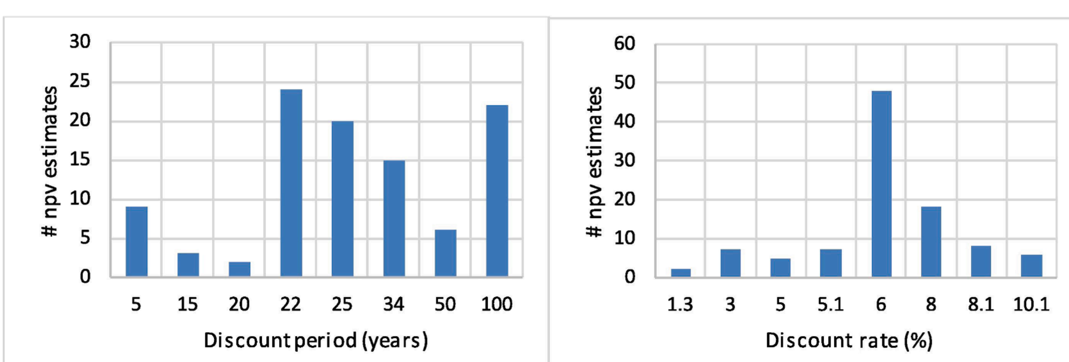

Fig. 2. The distribution of i) discounting periods (left), and ii) discount rates (right) of studies reporting NPVs.

Table 2
Summary of the benefits and costs of restoration by type of ecosystem (n >= 4).

	Benefits: R/ha/year							Costs: R/ha/year						
	Mean	SD	Q1	Q2	Q3	Q4	n	Mean	SD	Q1	Q2	Q3	Q4	n
Thicket	631	759	290	428	496	2 137	6	144	139	40	125	257	424	11
Fynbos	28	40	5	7	44	136	14	387	562	47	261	462	2 778	58
Rivers, lakes & water bodies	827	2 444	57	206	467	9 954	14	869	1 928	59	218	870	7 829	16
Savanna	605	1 030	297	783	2 283	3 165	12	106	111	63	97	150	322	7
Grassland	585	1 420	0	2	20	3 483	6	304	269	206	330	454	1 067	14
Succulent Karoo	312	689	1	33	83	1 717	7	296	678	96	143	230	3 136	20
Desert	58	124	19	23	28	363	16	92	69	47	60	111	303	18

the characteristics of these estimates vary significantly. The distribution of the discount period in years as well as the discount rates used in these are shown in Fig. 2. The length over which cash flows are discounted vary between 5 years and 100 years. The majority of NPV and PV estimations use a discount rate of 6%. Given the wide variance in the length over which restoration projects are discounted, comparisons of NPVs were not made.

3.3. Quantitative analysis

The $/ha/year statistics (mean, Q1, Q2, Q3 & Q4) organised by type of degradation are presented in Table A2 for all ecosystems where $n \geq 4$. The following salient facts emerge:

- The clearing of invasive alien plants is the type of degradation for which the most estimates are reported (34benefitestimationsand116costestimations).
- The Q2 value of the benefits is estimated at $19/ha/year while the Q2 of the costs is estimated at approximately $230/ha/year.
- Restoration to address overexploitation of fish stocks has the largest Q2 estimate for benefits, namely $180/ha, and the largest interquartile range, or difference between Q3 and Q1, of $4 250/ha in absolute terms.
- Restoration to address bush encroachment has the smallest Q2 benefit of 1$/ha and, in absolute terms, the smallest interquartile range $16/ha. Restoration to address bush encroachment is estimated to be the least efficient way to spend money on restoration, but the outcome of the restoration might be more certain, and it is expected to vary less between restoration sites.
- Soil erosion is estimated as the costliest type of degradation to restore, with the cost of Q2 estimated at $4 767/ha.
- Overgrazing and vegetation loss are estimated to be the least costly degradation types to restore, with the cost of Q2 estimated at $40/ha.

The $/ha/year estimates grouped by ecosystem are presented in Table 2 for all ecosystems where n >= 4 (converted using a spot rate of 1 $ = R15.44). This gives an indication of how data is distributed and whether the most observations in the dataset are low or high. The following is evident:

- The estimates of the benefits of restoration for Savanna and Thicket are always larger than restoration cost estimates.
- Restoration cost estimates for the Succulent Karoo always exceed benefit estimates.
- All Grassland benefits that have been estimated for South Africa are < $25/ha.
- More than half of the benefits estimated for Succulent Karoo and Fynbos are < $33/ha.
- Standard deviations calculated for data grouped by ecosystem are larger than mean values excluding costs for thicket, desert and grassland.

3.4. Estimating the net benefits of restoration by ecosystem

Based on De Groot et al. (2013), Blignaut et al. (2014) and Elmqvist et al. (2015), we calculated the net present value (NPV) of restoration by ecosystem using the values from Table 2. We compared the benefits of Q1 with the costs of Q1 and likewise for the other quartiles. The results are highlighted in Table 3. The NPV, for example, when comparing Q1 benefit and cost data for Fynbos is -$49/ha and such a restoration initiative will have an IRR of −2%. Of the 28 estimates, the NPVs of 8 were found to be negative. The estimate that yielded the highest NPV, $87 146/ha, is for Q4 of the Rivers, lakes and water bodies ecosystem. Internal rate of returns were calculated for cases where cash flows did not have the same sign or did not alternate between being positive and being negative.

Table 3
Summary of NPVs ($/ha over 25 years at a discount rate of 7%), with the internal rate of return (IRR) by type of ecosystem (n >= 4).

	Quartile 1		Quartile 2		Quartile 3		Quartile 4	
	NPV	IRR	NPV	IRR	NPV	IRR	NPV	IRR
Fynbos (n = 17 benefits; n = 58 costs)	-$49	-2%	-$507		-$564	-4%	-$4 762	
Rivers, lakes & water bodies (n = 14 benefits; n = 16 costs)	$467	50%	$1 682	49%	$2 964	26%	$87 146	68%
Savanna (n = 12 benefits; n = 7 costs)	$2 974	298%	$8 016		$23 657		$32 544	
Grassland (n = 6 benefits; n = 14 costs)	- $457		- $715		- $806		$34 228	27%
Succulent Karoo (n = 6 benefits; n = 20 costs)	- $205		$25	8%	$362	16%	$11 049	27%
Desert (n = 16 benefits; n = 7 costs)	$90	18%	$103	17%	$43	10%	$3 135	64%
Thicket (n = 6 benefits; n = 11 costs)	$2 958		$4 224	358%	$4 641	117%	$21 514	

4. Discussion

Restoration and the documentation of restoration outcomes are subject to several challenges that give rise to scepticism as to whether restoration is efficient, scalable, and beneficial to society. These challenges cannot be addressed through either ignorance or the absence of a concerted effort to develop robust databases. In seeking to abate this scepticism in the South African case, we set out to improve upon the study of Crookes and Blignaut (2019) which was the largest and most comprehensive *meta*-analysis of restoration studies for the country. To improve upon their study the sample size of cost and benefit estimates was expanded. During an initial inspection of the dataset we noted that, even after removing what we then suspected were outliers, there was evidence suggesting the distributions of cost and benefit estimates are skewed. Large variances in restoration cost and benefit estimates are common, and other researchers have acknowledged the potential skewness of estimate distributions (Droste & Meya, 2017; De Lange et al., 2018; Glenk & Martin-Ortega, 2018; Morokong et al., 2018; Stainback et al., 2020). There are appropriate adaptations such as the reporting of use of median restoration cost and benefit values to inform decision making (Bayraktarov et al., 2020). Yet, even in international studies there remains a strong habit to sample restoration costs and benefits during model simulations from normal distributions (Calder et al. 2019), use mean values in computing NPVs (Gasparinetti et al., 2022) or in calculating benefit cost ratios (Elmqvist et al., 2015). Even where means and median values suggest skewed cost and benefit estimate distributions, methods to identify and remove outliers remain unchallenged (Su et al. 2021). The removal of outliers or use of the mean have large consequences pertaining to the correct interpretation and representation of data. Where distributions are skewed, the mean is not a good measure of central tendency and is inappropriate to report, use in subsequent analysis, or inform decision making (Lydersen, 2020). Where distributions are skewed the practice of removing data points as outliers is considered bad practice (Walfish, 2006).

Reporting or use of median values to calculate NPVs or benefit cost ratios may fall short of satisfying sceptics of restoration. To inform the desirability of restoration in South Africa, we opted to use the quartile benefit and cost estimates to calculate four NPV/ha values per ecosystem type (Table 3). In discussing these NPVs we demonstrate the potential value of this approach in informing restoration desirability.

For South Africa, positive NPVs and IRRs suggest that ecological restoration is beneficial and desirable for savanna, thicket, desert, river, lake, and waterbody ecosystems. The sample size for the Nama Karoo was considered insufficient for analysis (n less than 4). The exclusion of the Nama Karoo is a large limitation to this study, as an initial valuation for restoration desirability over a fourth of South Africa's land mass is omitted. The negative NPVs calculated for grasslands, succulent karoo and fynbos altogether comprise 35% of the country's landmass and are of particular interest (Statistics South Africa 2020).

The negative NPV for grasslands should be interpreted bearing in mind that the number of benefit estimates observed for Grasslands is small (n = 6). When ranked, the first three valued restored grasslands for their food provisioning benefit alone at under at 1$/ha. The next two estimates valued restored grasslands for their water supply value at $3/ha and $26/ha. The largest estimate includes restoration values for medicinal resources, water supply, water regulation, grazing and livestock fodder cultivation benefits, and values restored grasslands at $3483/ha. Where water supply and grazing benefits of restoration are considered, grassland restoration projects in South Africa have negative NPVs and a negative internal rate of return (-17% Table 3). A positive NPV for ecological restoration is observed with Q4 values, where four ecosystem services were valued. It is possible that the largest of the five benefit entries is due to calculation or reporting error (it is 133 times larger than the second largest in the sample). However, it is also possible that the medicinal resource value of grasslands is substantial. Maroyi (2022) provided evidence that people living in the grasslands ecosystem value provisioning services above regulating services and place a higher value on plants harvested for medicinal purposes than they do on plants harvested for food or building materials.

There are 14 cost estimates for grassland restoration that range between $2/ha and $1067/ha. The largest cost estimate is for gully restoration using gabions, which is the most expensive restoration intervention in the entire sample. The two lowest entries are for revegetation. The majority of cost estimates are for invasive alien plant removal (n = 11) reflected from Q1-Q3. South Africa has an extensive invasive alien plant removal program, and the cost-effectiveness and desirability of invasive plant removal have been the subject of debate for the past two decades (McConnachie et al. 2012; Van Wilgen et al. 1997). Invasive alien plant removal in South Africa rest on the value of increasing mean annual runoff in water stressed catchments. At Q2 and Q3, costs reflect invasive plant clearing and benefits estimate water supply values Here negative NPVs are calculated. Where the most expensive grassland restoration intervention is used along with the largest restoration benefit estimate, including medicinal resources, grazing value, water supply value, and fodder provisioning values, a positive NPV is observed. It is possible, that the adequate justification for restoration of grasslands in South Africa requires greater emphasis on quantifying medicinal resource benefits of restoration along with fodder provisioning benefit values.

A negative NPV was also observed for the succulent karoo ecosystem, when cost and benefit estimates are taken at Q1. There is a larger sample of cost estimates observed for the succulent karoo (n = 20) compared to benefit estimates (n = 6). Of the six restoration benefit estimates, three are less than $1/ha, two lie between $1/ha and $100/ha and one estimate is for $1717/ha. Ranked from smallest to largest, the first four estimates are made for the benefit of restoration in improving grazing in the succulent karoo. The following two larger estimates include recreational values, water flow regulation and water supply value of restoration, and amenity value. A large portion of the succulent karoo ecosystem is under the control of private landowners and is used predominantly for livestock farming (Hoffman et al. 1998). Due to the succulent karoo's low rainfall and vegetation composition, this ecosystem has a low livestock carrying capacity and low productivity compared with grassland ecosystems (du Toit 2002). Estimating the per hectare restoration benefit of the succulent karoo based on food provisioning values will yield low estimates. As most of the succulent karoo is under the control of livestock owners, the benefit of grazing could be the deciding factor in restoration investment by landowners.

Fynbos had negative NPV calculated for all quartiles. The sample is large, with 58 cost estimates and 14 benefit estimates. All restoration case studies from which cost estimates were extracted were for invasive alien plant removal. All but one benefit estimate was made for water benefits from invasive plant removal. In the larger database, positive (Holmes et al. 2007) and negative (Hosking and Du Preez, 2004) NPVs have been calculated for fynbos restoration projects. Even when including a wide range of ecosystem services, fynbos restoration is found financially justified only under specific conditions, such as where mild restoration was applied or the rapid commercial realization of water and tourism benefits from restoration is assumed (Fourie et al. 2013; Currie et al., 2009). The literature provides support to the notion that the profitability of fynbos restoration will require benefit values per hectare that estimate the sum of several ecosystem services while incurring low costs. If the largest cost estimates could be excluded as outliers (all three exceeding $1000/ha in value) then positive NPVs emerge at the second and third quartiles. There is no justification for their exclusion. All cost estimates are for operating costs occurring during invasive alien plant clearing.

The fynbos ecosystem makes up less than 7% of South Africa's landmass but has produced the largest share of restoration cost and benefit estimates. Though well loved, the data collected and analysed here do not suggest invasive alien plant clearing in fynbos to produce only water benefits alone is desirable. It is important to reiterate that the

NPVs calculated for fynbos restoration were not analysed here or compared for the reasons stated above. Only the R/ha/year cost and benefit values that were reported in restoration case studies. There is a need for researchers to quantify ecosystem service restoration benefits in Fynbos other than water supply.

The South African database reported on here has the clear-cut fingerprints of various yet unrelated institutional interventions. The development of studies and the recorded number of estimates of the benefits and costs of restoration can be related back to these institutional interventions, suggesting that far greater attention should be rendered to such interventions. The importance of these interventions is of such a nature that they deserve further discussion.

First, South Africa commenced with a public works programme on restoration, called Working for Water, in 1995. This programme focussed on the removal of invasive alien plant species to enhance water security. While criticised considerably (Hosking & Du Preez, 2004), it has been central in shaping efforts of scientific enquiry into the efficiency of ecological restoration. It is therefore not surprising that the earliest papers in the database focus on the evaluation of restoration to remove invasive alien plants (Higgins et al., 1997), and that it is the subject of most of the research papers in the database (see Table A1).

The impact of the Working for Water programme, especially in its early years, can clearly be seen in Fig. 1. The spike in the number of benefit and costs estimates in the year 2000 was because of a conference held by the programme February of that year. The aim of the conference was to mobilise stakeholders to take an active role in the development of methods and practices to monitor, control, and evaluate the ecological restoration of invasive alien plant species (Preston et al., 2000).

After the spike in 2000, a steady increase in the number of observations can be seen from the year 2010 onwards, the year in which The Environmental Economics of Biodiversity (TEEB) report was released (see also De Groot et al., 2010, 2012). This coincided with, first, an increase in the public works expenditure linked to South Africa hosting the 2010 Soccer World Cup, and, second, the Working for Water program providing support to the Restoration of Natural Capital (RNC) project between 2008 and 2012. This project sought to foster knowledge development between the many academic disciplines and institutions to stimulate the production of these evaluations of restoration (Esler et al., 2016). The number of papers published, especially in 2008 and 2012 benefited from this project. The RNC project was followed by another concerted effort by Working for Water between 2016 and 2020 leading to the addition of 32 papers containing cost and benefit estimates.

These institutional interventions provide a very good explanation of the trend in the production of these estimates over time and highlight the importance of conferences, think tanks and public works programmes to support knowledge generation in this field.

5. Conclusion

The need for restoration to address the consequences of degradation is prioritised at a global stage. Not only because of the negative effects degradation is causing with respect to a loss in ecosystem goods and services, but also because of the opportunity costs associated with the lost economic opportunities because of such degradation in the form of the productive capacity of the land, jobs, income, etc., and the economic benefits that are forfeited. It is therefore important to consider, at a local level, what the economic benefits and costs of restoration are. Compared to their need, however, estimates for restoration benefits and costs are scarce. Where such reporting is being done, habits govern their reporting methodologies with a heavy reliance on reporting only NPVs and not the underlying data. Most importantly, there persist within the international community a strong use of means and standard deviations without considering data skewness. This further shrouds the efficacy of estimate reporting and subsequent analysis.

By calculating and reporting NPVs based on quartiles, and remaining mindful of differences in ecosystem service values, one can easily identify conditions and thresholds that which would make restoration a sound investment. When applied to South Africa, the evidence indicate that the benefits of restoration do exceed in most cases, a concerted effort should thus be made to implement a country-wide restoration programme to the benefit of both the current and future generations. In support of this we recommend that more research be conducted in those cases where there are only a few observations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A

Table A1
Description of cost and benefit estimates in the database.

Unit of measure	#C&B	Type of degradation	#C&B	Type of cost	#C	Type of benefit	#B
Rand/year	112	IAPs	275	Operating cost	119	Water supply	87
NPV (Rand)	95	Changes in land cover	56	Total management cost	35	Food provisioning	42
Rand/ha/year	50	Other	31	Once-off capital cost	20	Tourism and recreation	15
Rand/ha	36	Soil erosion	17	Other	20	Carbon sequestration, storage	13
$/ha/year	35	Bush encroachment	15	Research cost	14	Fodder provisioning	13
PV (Rand)	28	Unspecified	13	Opportunity cost	14	Amenity values	11
Other	22	Mining	11	Unspecified	10	Harvested renewable resources	10
$/# years	15	Reduced water flow	10	Equipment and labour	7	Construction material	8
$/year	13	Overgrazing	9	Labour cost	6	Meeting conservation objectives	6
Rand	11	Overexploitation of fish stock	5	Material cost	5	Wood fuel for energy	6
$	9	Declining water quality	3	Sundry cost	3	Medicinal plants	4
R/30 ha	9	Pollution	2	Material and production cost	3	Genetic diversity	4
NPV ($)	6					Critical habitats	4
PV ($)	6			Seed dispersals	4		
				Existence and bequest	2		
				Ornamental resources	2		
				Waste quality amelioration	1		

Note: For the sample of 76 papers, this table counts the number of times a unit of measure is used, the type of degradation it focussed on, the types of cost reported, and the types of ecosystem service benefit that were estimated.
#B = number of benefits; #C = number of costs

Table A2
Summary of the benefits and costs by type of degradation (n ≥ 4).

	Benefit ($/ha)							Costs ($/ha)						
	Mean	Std.	Q1	Q2	Q3	*Q4*	*n*	Mean	Std.	Q1	Q2	Q3	*Q4*	*n*
Invasive alien plants	140	438	4	19	89	9 954	34	766	2 402	69	230	455	17 271	116
Changes in land cover	1 974	2 316	333	1 616	2 698	2 545	20	1 643	3 006	126	285	1 394	17 271	20
Mining	248	261	30	97	464	689	11							
Overexploitation of fish stocks	2 684	2 297	464	2 782	4 714	5 183	5							
Overgrazing								117	141	32	40	175	424	9
Soil erosion								7 136	6 509	2 051	4 767	12 800	18 384	12
Vegetation loss								100	89	20	105	140	316	14
Bush Encroachment	17	0	1	1	17	4	14							

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