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Restoration of water resources (natural capital) through the clearing of invasive alien plants from riparian areas in South Africa — Costs and water benefits

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Abstract

Working for Water forms part of the Expanded Public Works Programme of the South African Government, aimed at the sustainable management of natural resources through the control and management of invasive alien plants while enhancing socio-economic empowerment in South Africa. The programme's name was taken from one of the original motivations: namely, reducing the impacts of invasive alien trees on water resources. A number of studies have looked at the potential impacts of the programme but only one or two have used actual management data to quantify its costs and benefits. This paper is the first, in hopefully a series of papers, on the costs and impacts of the programme over recent years. The paper focuses on the extent, costs and impacts of clearing invasive alien plants from riparian areas. Data were extracted from the Working for Water Information Management System (WIMS) and analysed to assess clearing costs and estimated impacts of clearance on water resources. Some of the most significant findings of the study again illustrate the need to treat invasions as early as possible. Very scattered (1–5%) invasions of selected species for example were between 3 and 25 times cheaper to clear than closed canopy stands (75–100%). On the other hand, unit reference values, used to compare clearing operations in terms of cost efficiency in generating extra water yield, were much higher for low levels of invasion than denser invasions, to the extent that the former's viability could be questioned by the uninformed. However, this was only assessed in terms of extra water generated and not in terms of volumes of water secured, as invasive alien plants spread and become denser if not actively controlled. If left unchecked, water losses increase, which makes the clearing of light infestations much more viable. Overall, it is estimated that around 7% of riparian invasions have been cleared, resulting in significant yield increases. The increased estimated yield of 34.4 million m^3 is about 42% of the yield of the new Berg River Scheme in the Western Cape (81 million m^3). The investment in clearing species known for excessive water use from riparian areas, at a cost of *R*116 million, was found to be a very good investment. However, it is important to note that the clearing of invasive alien plants will seldom result in the total elimination of shortfalls in water supply and should be seen as part of a package of water resource options to optimize supply, aimed at minimizing wastage of water.

Keywords: Clearing unit reference values; Costs; Invasive alien plants; Net present value; Person days; Riparian; WIMS; Workload

1. Introduction

The Working for Water Programme (WfW), initiated in October 1995, aims to restore and maintain natural resources by clearing invasive alien plants while creating jobs and economically empowering unemployed people from historically-disadvantaged communities. The programme's name derives from one of the motivations used to convince the then minister of Water Affairs and Forestry to support the programme: that of conserving water. At that time, Versfeld et al. (1998) estimated that invasive alien plants reduced South Africa's mean annual runoff by some 7%. Since then, a number of studies have attempted to quantify the costs and benefits of the programme, focussing mostly on water and the losses as a result of doing

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nothing. However, many of these assessments did not focus on specific interventions and their impacts. Marais et al. (2004) were the first to make an attempt to quantify the costs of the programme to some extent, but at that stage not enough data were available to do a focussed assessment of specific interventions and these interventions' impacts on specific benefits. Before and since the programme's inception, a number of studies were done focusing on localized impacts of clearance on natural resources. Dye and Poulter (1995) found a substantial increase in stream flow after clearing *Pinus patula* and *Acacia mearnsii* from riparian areas in Mpumalanga. The results showed that stream flow increased by 12 m^3/ha/day immediately after clearing. This work was followed up by Prinsloo and Scott (1999), who found that stream flow increased by 9, 10 and 12 m^3/ha/day in Du Toits Kloof (near Paarl), Oaklands (near Wellington) and Somerset West in the Western Cape respectively, after clearing Australian *Acacia* and *Eucalyptus* species from riparian areas. Dye and Jarmain (2004) looked at net changes in total evaporation, and found invasive alien tree stands to increase evaporation by 1570 to 4240 m^3/ha/annum compared to natural vegetation.

Görgens and Van Wilgen (2004) did an assessment of the current understanding of invasive alien plants on water resources, referring to, amongst others, the above studies and a series of studies on long-term effects of forestation on water resources. Using these assessments, two studies by Cullis et al. (2007) and Blignaut et al. (2007) looked at the implications of invasive alien plant management in the mountain catchment areas (watersheds) and riparian zones for water users in South Africa.

In addition to the impact on water resources, Samways and Taylor (2004) reported significant impacts of clearance on the recovery of the endemic Dragonfly (*Odonata* species) populations. According to this study, of the 31 endemic Southern African Dragonflies, 12 are globally Red Listed and 11 of these are threatened by alien plant invasions in riparian areas. The study found that Dragonfly populations recover rapidly after the clearance of dense stands of Black Wattle. This is but one example of the biodiversity impacts of invasive alien plants in riparian areas.

The Working for Water Programme (WfW), now (2007) in its 12th year, has made significant impacts on the sustainable management, control and containment of invasive alien plant species through its expanded public works clearing projects, biological control programme and inputs to establish a sound legislative framework for the management of invasive alien species. Up to the 2005/06 financial year, the programme has spent more than *R*3.2 billion, creating temporary employment opportunities for up to 30,000 people per annum and clearing more than 1.6 million ha of land (1.666 million initial clearing, and followed up on average 1.83 times, or 3.056 million ha of follow-up treatments — 1 initial + ≈ 2 follow treatments). In order to assess the impacts of this work, it is necessary to look at the impacts across biomes and positions in the landscape. This paper focuses on some costs and benefits of clearing invasive alien plants from riparian areas of South Africa.

2. Materials and methods

2.1. WIMS — Working for Water Information Management System — the database — estimating the overall costs of clearance

The data used for this paper were extracted from WfW's management database, WIMS. All clearing being done by the programme is (now) captured in this database. It was developed on a Geographical Information System (GIS) platform and records alien plant species, densities, costs and person days planned and worked on a specific area (polygon). The database design is *one-to-many* meaning that more than one species and its density can be recorded per polygon. It generates clearing contracts by adding the estimated workload of one or more polygons until the total area is a manageable size for an emerging contractor to clear over a specified period. This is normally the area a contractor, with around 10–15 labourers, can clear in a month. This means that some assumptions need to be made when analysing the data. Firstly, the cost allocation is then per contract, based on the total number of planned person days allocated across all polygons covered by the contract. Furthermore, person days are allocated per species and their densities within and across all polygons per contract.

In order to allocate costs per treatment to specific species, the dominant species per polygon was selected to use as the indicator for natural resource impacts. Generally the dominant species drives the costs as they normally make up more than 50% of the total invasive stand. Cost allocation per polygon was calculated using a simple formula to allocate costs to polygons proportional to their contribution to total contract costs.

$$CP = PdP / PdC \times CC$$

where:

CP	Cost of Polygon
PdP	Person days Planned for polygon
PdC	Person days planned for whole Contract
CC	Cost of Contract as whole.

Workload, or person days per treatment, per polygon were simply derived by adding all person days allocated to a specific polygon. Three variables can then be derived from this data: planned workload (person days) per hectare, actual workload per hectare and costs per hectare. For the purposes of natural resource restoration and management, the latter two are most important. In order to assess the costs and impacts of WfW clearing in riparian areas on water resources and biodiversity (initial and follow-up treatments), the costs per treatment per ha and the workload per treatment per hectare were calculated.

As can be expected from a developing data set such as WIMS, there are some shortcomings. The first challenge was the fact that some of the polygons did not receive an initial treatment according to the data extract. This is explained by the fact that the database was only initiated in 1998 and only became fully functional in 2002/03. Earlier data were recorded in manual systems such as spreadsheets. It was, however, not necessary to discard this data because the follow-up data could still be used. The final dataset, therefore, included initial clearing records from some regions from as early as September 1998 and as late as August 2006.

The second shortcoming was that of incomplete records, especially the workload data where the actual person days worked on a polygon was missing from the data set. This could be overcome as follows. We know that an amount could only be entered in the record if the area had been treated. The data gaps in workload fields were filled by dividing the overall average cost per person day by the contracting cost per polygon. This gave an estimate of the number of person days worked in a specific polygon where the data had been omitted from the main database.

2.2. Extent of clearing in riparian areas

There are approximately 153,800 km of rivers in South Africa (CDSM, 2000). Cullis et al. (2007) assumed perennial riparian areas to be 0.5% of the surface area of South Africa and riparian areas associated with non-perennial rivers to be 0.25%. They assumed the average width of perennial riparian areas to be 83 m and that of non-perennial riparian areas to be 41 m based on surveys done on some rivers in the Western Cape during the period 1996–1998. The total invadable riparian area in South Africa was therefore estimated to be around 857,200 ha, of which 572,600 ha are on perennial, 253,900 ha are on non-perennial and around 30,800 ha are on unclassified rivers (CDSM, 2000).

To assess the extent of clearing in riparian areas captured in the database, all polygons that overlapped with rivers were assumed to be riparian. It is important to note the data does not represent the total extent of riparian clearing done by WfW during the study period: only those areas captured in the system as the regions came on-line. At the moment though, and in future all areas will all be captured as the WIMS system is fully operational.

2.3. Clearing costs for some important genera

The initial assessment of clearing costs reported by Marais et al. (2004) showed that the costs for different genera across a range of density classes vary significantly. In order to estimate the cost of clearing in more detail, the data were sorted per genus. The respective genera were then analysed individually. The most important species and some species indicative of a specific type (e.g. sprouting large trees, sprouting medium sized trees, large non-sprouting trees and sprouting shrubs) were then analysed in more detail. The genera selected were the Australian *Acacia* tree species, as it is the genus treated most by WfW, *Eucalyptus* because of its reputation as a major water user, *Chromolaena* representing shrubby species and *Pinus* representing non-sprouting species.

There are major variances in costs and workloads across density classes and genera. However, for the results of this study to be used in large-scale planning and impact assessments, it was decided to simply sort the data per individual genus per density class. The density classes of projected canopy cover are the ones used by WfW in its medium to long-term management and annual plans of operation: Rare (0–0.1%), Occasional (0.1–1%), Very Scattered (1–5%), Scattered (5–25%), Medium (25–50%), Dense (50–75%) and Closed (75–100%). For the purposes of this study, the rare and occasional density classes were combined as the treatment costs and impacts are generally of the same order.

Some assumptions need to be made to calculate the average follow-up costs. Polygons differ in the number of follow-up treatments despite having a similar initial density. Some might receive only one treatment (as in the case of non-sprouting species at all densities) while others (as in the case of sprouters at high densities) have received up to eight and more treatments.

Table 1
Total extent (ha) of riparian clearing operations per genus recorded in the WfW database 1997/98–2005/06

Genus	Area treated	Condensed area[a]	Initial density of invasion	Total cost of treatment (millions)	Estimated overall cost of treatment (millions)
Acacia spp.	71,795	9354	13.0%	*R*45.14	*R*62.51
Cereus spp.	48,249	8389	17.4%	*R*1.98	*R*2.75
Prosopis spp	25,284	4840	19.1%	*R*12.50	*R*17.30
Chromolaena odorata	18,085	4330	23.9%	*R*13.66	*R*18.92
Lantana camara	15,303	3283	21.5%	*R*10.30	*R*14.26
Eucalyptus spp.	6736	1982	29.4%	*R*10	*R*13.85
Pinus spp.	36,029	1634	4.5%	*R*5.15	*R*7.13
Solanum spp.	5238	1521	29.0%	*R*5.58	*R*7.72
Populus spp.	2295	929	40.5%	*R*5.95	*R*8.24
Hakea spp.	18,197	903	5.0%	*R*2.74	*R*3.79
Melia azederach	3633	867	23.9%	*R*5.10	*R*7.06
Opuntia spp.	19,608	582	3.0%	*R*1.14	*R*1.58
Caesalpinia spp.	1985	446	22.5%	*R*2.05	*R*2.84
Rubus spp.	1360	281	20.7%	*R*1.34	*R*1.85
Psidium guajava	2568	271	10.5%	*R*1.70	*R*2.35
Salix spp.	363	247	67.9%	*R*0.55	*R*0.76
Jacaranda mimosifolia	1073	229	21.3%	*R*0.79	*R*1.11
Eichhornia crassipes	1140	175	15.4%	*R*1.23	*R*1.70
Sesbania punicea	460	163	35.6%	*R*0.51	*R*0.70
Arundo donax	378	127	33.5%	*R*0.96	*R*1.33
Ricinus communis	1153	125	10.8%	*R*0.75	*R*1.04
Agave spp.	1467	95	6.5%	*R*0.66	*R*0.91
Cestrum spp.	143	93	64.9%	*R*0.38	*R*0.53
Alien spp. (Dominated by Acacia mearnsii)	21	12	58.2%	*R*0.17	*R*0.23
Other species	6393	775	12.1%	*R*3.57	*R*4.94
Total	288,955	41,653	14.4%	*R*133.92	*R*185.42

[a] % Invasion as a proportion × area of polygon expressed as the equivalent of a 100% cover.

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It may overestimate costs to simply calculate the workload and cost based on the polygons listed in the database under the specific treatment. The costs and workload per hectare were, therefore, calculated using the total area treated in the initial treatment phase. Only polygons with an initial treatment recorded were included in the analysis of treatment costs per hectare for individual species. If a polygon is not treated in the next follow-up, it was assumed that it has been handed over to the land user (exited). On private land, until recently, this has taken place after the second or third follow-up treatment. On state land however, a polygon generally stays in the clearing programme for longer, as in the case of national parks, state forests and provincial nature reserves.

2.4. Extent of riparian clearing in the biomes of South Africa

The riparian clearing polygons were simply overlaid on the Mucina and Rutherford (2006) biomes to get estimates of the impact of WfW clearing operations in respective biomes of South Africa. This analysis only used the data on the biome and genus, and condensed hectares as the indicator of overall extent or density.

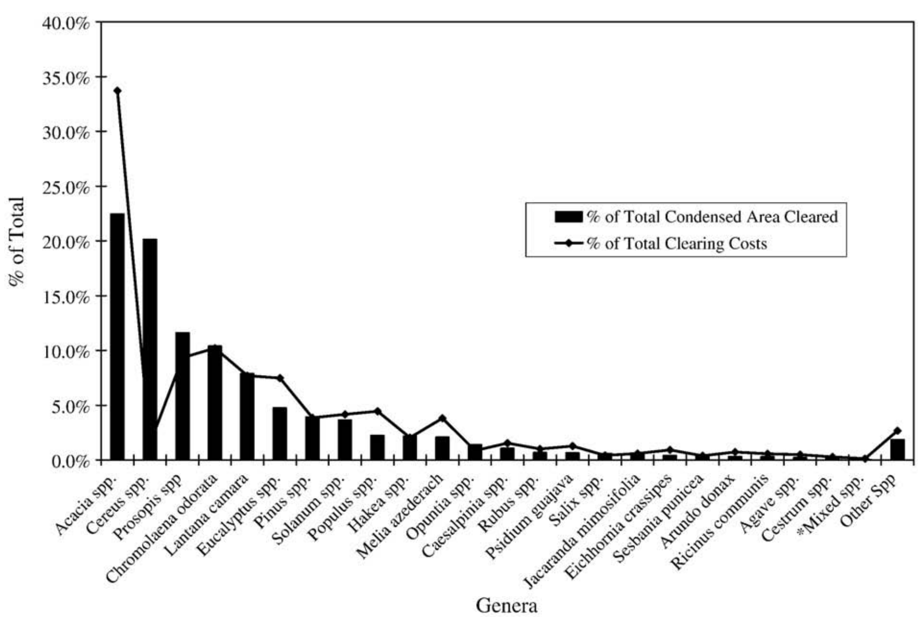
2.5. Extent of clearing in species known for excessive water use and impact on water resources

The impacts of some invasive alien plant species on stream flow have been measured but for many others, there are no data and the impacts have to be estimated from the attributes of the species and its habitat. In order to assess the impacts on water resources, the clearing costs of some species were ignored. Le Maitre et al. (2004) used this information to estimate the impacts of a number of invasive species on water resources in terms of their potential transpiration rates. Tall trees were assigned a score of four and other trees, shrubs and aquatic plants were given a score of three. Grasses, reeds and herbs were assigned a score of two. Climbers and scramblers, as classified by Henderson (2001), were assigned the lowest score of one, with the exception of *Lantana* and *Chromolaena,* which were given a score of three because of their ability to reach a high biomass. Table 1 shows the genera assessed in this paper and their scores based on Le Maitre et al. (2004). Only those species listed as high-impact species by Le Maitre et al. (2004) were used in the assessment of impacts on water resources. For the purposes of this study, genera included in the list of those impacting negatively on stream flow and cleared from riparian areas are: *Acacia, Eucalyptus, Melia, Pinus, Populus* and *Prosopis*.

The impact of clearing on water resources was estimated by assuming that, once an area was treated, the water benefits would be realized. This assumption is based on the WfW management policy of following areas up as soon as possible, to prevent the regenerating alien plants from maturing and reproducing. It can therefore be assumed that the water use of the stand is being suppressed until it is under full control.

The water-resource impact of each treatment was standardized by converting the extent to condensed hectares (% Invasion as a proportion × Area of Polygon). This is then expressed as the equivalent of a 100% cover.

The impact on water resources (stream flow) was estimated using the assumptions made by Cullis et al. (2007) for riparian areas. Stream flow reduction from riparian areas is assumed to be 3000 m^3/ha/annum for perennial rivers and 1000 m^3/ha/annum for non-perennial rivers. This is similar to the stream flow reductions as assessed by Görgens and Van Wilgen (2004). Long-term stream flow reductions due to afforestation and



* Often dominated by *Acacia spp.*

Fig. 1. Initial condensed area treated in relation to clearing contract costs.

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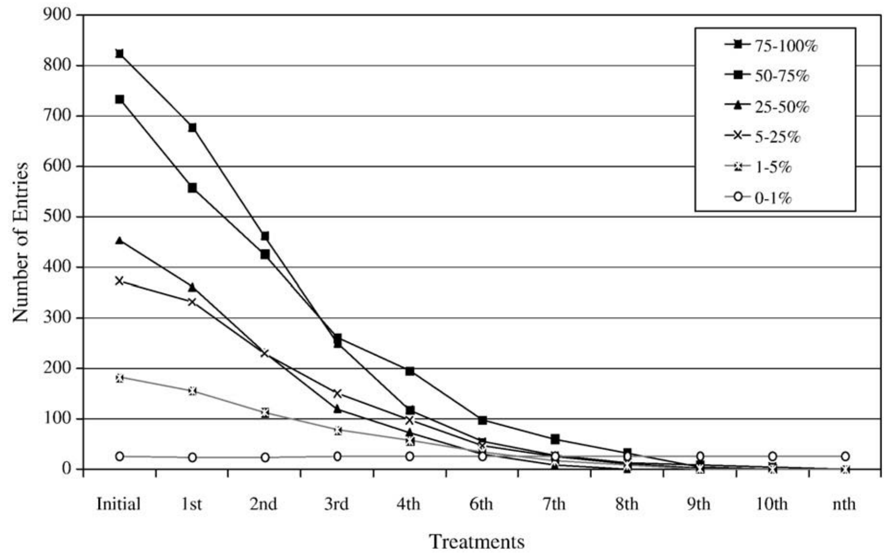

Fig. 2. Decline in data entries per follow-up treatments illustrating the impact of follow-up on extent.

invasion by alien plants vary: 2000 m^3/ha/annum in Limpopo (Savanna Biome), 2600 m^3/ha/annum in the KwaZulu Natal Drakensberg (Grassland Biome), 2800–3400 m^3/ha/annum in different sites across Mpumalanga (Savanna and Grassland Biomes) and 1300–3000 m^3/ha/annum in the Western Cape (Fynbos Biome). This is in line with the evaporation and changes in stream flow deduced by Dye and Jarmain (2004).

In order to estimate the effect of riparian clearing on water yield in the respective regions, the assumptions used by Cullis et al. (2007) for riparian areas were again applied: that water loss from the riparian area has a direct effect on the so-called *run of river use* (i.e. the water that is available for use). The reduction in yield (or utilizable water) is assumed to be 75% of the reductions in stream flow, an assumption accepted by water

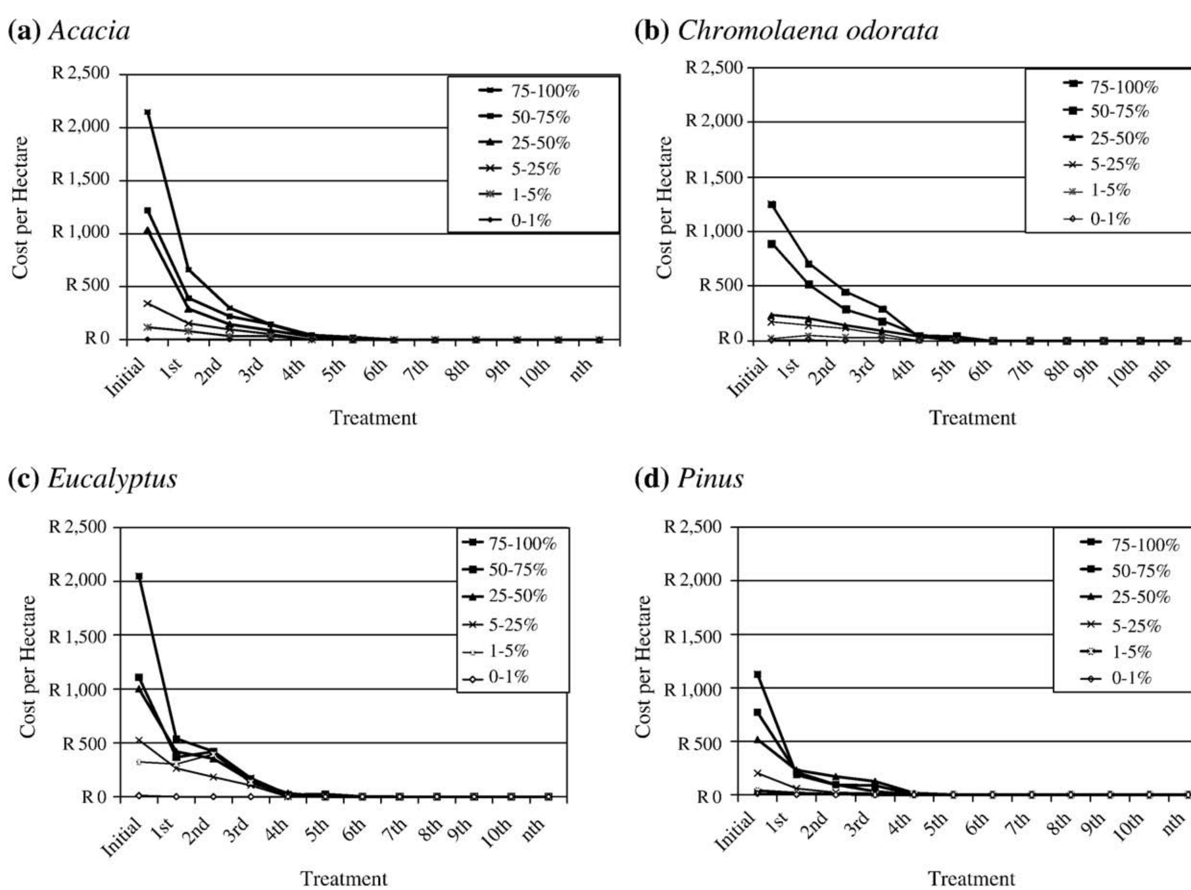

Fig. 3. *Acacia spp.* Average cost per hectare for initial and follow-up treatments for all density classes for initial area treated.

engineers for water resource planning purposes (Cullis et al., 2007).

To simplify the assessment, some assumptions had to be made about the extent of clearing in perennial rivers and non-perennial rivers. Cullis et al. (2007) estimated that 67% of all riparian areas are on perennial rivers and the other 33% on non-perennial and unclassified rivers. To get a more accurate estimate of the perennial and non-perennial clearing, the length of rivers covered by the cleared polygons were used to estimate the percentage perennial and non-perennial clearing per water management area. The increased yield per condensed hectare cleared was therefore assumed to be 2250 m^3/ha/annum for perennial clearing and 750 m^3/ha/annum for non-perennial rivers. The reason for the difference is that in perennial rivers, plants never come under water stress, as there is always water available in the system, whereas non-perennial rivers can be compared to upland invasions where periodic droughts may be experienced. Görgens and Van Wilgen (2004) reported that the clearing of trees in riparian areas resulted in a stream flow increase of twice as much as upland clearing in Limpopo and Mpumalanga and more then three times as much in the Western Cape.

We compared clearing operations in the different water management areas using a method similar to that used by water resource managers to compare the feasibility of alternative augmentation schemes (Blignaut et al., 2007). The Unit Reference Values (URVs) for clearing in each Water Management Area were calculated by applying the following formula to each catchment:

$$\text{URV} = \{\text{Present value of all costs in Rand incurred over the economic lifespan of the project}\} / \{\text{Present value of the total water sales multiplied by the appropriate water tariff over the economic life span of the project}\}.$$

When calculating the URV, cognisance of the following aspects should be taken:

- The economic life of water development projects is generally between 30 and 50 years; here we use 45 years.
- The cost component includes capital cost, i.e. the upfront cost of initial clearing of invasive alien plants and the cost of the subsequent follow-ups plus the annual operations and maintenance costs that include labour, land, or resource management cost.
- The benefit component is the product of the increased yield after initial clearing times the raw water tariff.
- A range of discount rates, namely 4%, 6%, & 8%, is used.

A URV of greater than 1 indicates that the present value of the cost of the project exceeds the present value of the water sales and *vice versa*. A URV of 1 is break-even. While no benchmark URV values exist for “good” and “bad” projects, a typical water development URV in the built environment is between 2 and 4.

Estimating the overall costs and benefits of riparian clearing requires inclusion of overhead costs in addition to the clearing contract costs. As the clearing costs recorded in the database only reflect the direct contracting costs, and do not include management overheads and chemicals, an adjustment had to be made with regards to clearing and maintenance costs. The following formula was used:

$$TC = \text{TCC} \times (\text{TCPd}/\text{TCCPd})$$

where

- TC = Total Cost of Clearing selected (high water users) species from the riparian areas in a given Water Management Area.
- TCC = Total direct Contracting Cost of clearing selected species from the riparian areas in a given Water Management Area.
- TCPd = Weighted average person day cost in WfW for the period 1997/98–2005/06 (the average over the period 1997/98–2005/06 of the total annual expenditure of WfW over the annual total number of person days of employment).
- TCCPd = Average contracting cost per person day for all polygons cleared in riparian areas and recorded in the WfW database between 1997/98 and 2005/06.

The average clearing contract cost per person day for all polygons was *R*108.76. The average annual cost per person day for the programme as a whole, for the period 1997/98–2005/06 was *R*150.21.

3. Results

3.1. Overall costs of clearing

In total, some 290,000 ha in riparian zones were treated over the period discussed here. Expressed as condensed hectares, this

Table 2
Summary of the treatment costs and workload for selected species illustrating the impact of density on costs and workload

Activities	*Acacia*	*Chromoleana*	*Eucalyptus*	*Pinus*
Total cost for 75–100% density (*R*/ha)	*R*3301	*R*2755	*R*3201	*R*1,491
Initial clearing costs (*R*/ha)	*R*2,148	*R*1251	*R*2049	*R*1127
Sum of follow-up clearing costs (*R*/ha)	*R*1153	*R*1503	*R*1152	*R*364
Total workload for 75–100% density (person days/ha)	33.89	32.69	30.91	12.37
Initial workload (person days/ha)	21.95	15.83	18.10	8.86
Sum of follow-up workload (person days/ha)	11.94	16.85	12.81	3.51
Total cost for 1–5% density (*R*/ha)	*R*266	*R*127	*R*1,155	*R*59
Initial clearing costs (*R*/ha)	*R*117	*R*20	*R*323	*R*38
Sum of follow-up clearing costs (*R*/ha)	*R*149	*R*107	*R*832	*R*21
Total workload for 1–5% density (person days/ha)	2.42	1.65	11.51	0.34
Initial workload (person days/ha)	0.83	0.20	2.62	0.20
Sum of follow-up workload (person days/ha)	1.60	1.44	8.90	0.14
Ratio of costs (75–100%:1–5%)	12.39	21.73	2.77	25.33
Ratio of workload (75–100%:1–5%)	13.98	19.87	2.68	36.36

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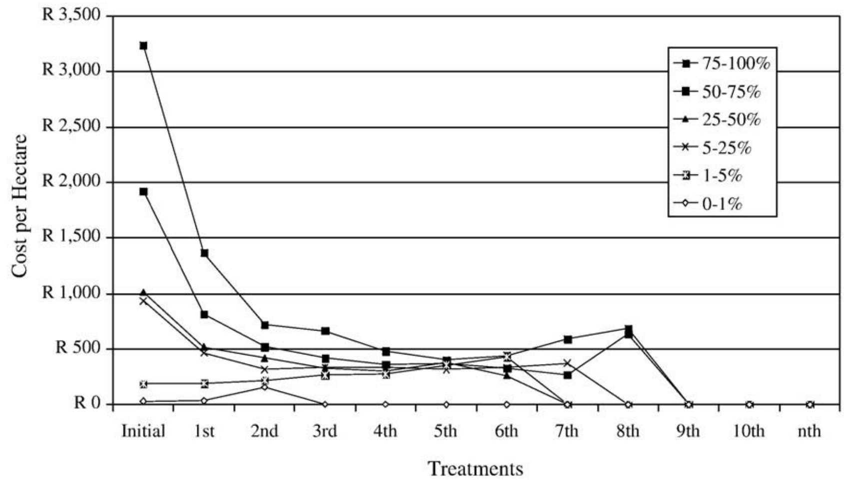

Fig. 4. *Acacia spp.* Average costs per hectare for initial and follow-up treatments for all density classes but calculated based on area treated for treatment and not initial area treated.

equates to 41,653 ha or a weighted initial density of 14.4%, at a contracting cost of *R*134 million and an estimated total cost of *R*185.4 million (Table 1).

Acacia is by far the most frequently treated genus (22.5% of condensed ha) with *Prosopis* (11.6%) and *Chromolaena* (10.4%) also being important species. However, the % of expenditure (nearly 34%) on *Acacia* is significantly higher than the percentage of the total area, while the expenditure on *Prosopis* and *Chromolaena* is more in line with the areas treated expressed as % of the total, at 9.3% and 10.2% respectively (Fig. 1). Both *Acacia* and *Prosopis* are known to be high water users. As reported by Marais et al. (2004) *Cereus* species (Queen of the Night) again emerged as being treated extensively but its clearing cost is insignificant compared to those of the above genera. Genera assumed, in this study, to have a significant impact on stream flow made up 47.1% of the total condensed area treated, but 62.7% of expenditure. Some species which were assumed not to have significant impacts on stream flow, might still turn out to have significant impacts once they are scientifically tested (e.g. *Jacaranda mimosifolia, Arunda donax* and *Salix* species).

3.2. Clearing costs per genus and densities

To show the effect of genus and densities on the cost of clearing, only some of the more significant genera (*Acacia*, *Eucalyptus*, *Chromolaena* and *Pinus*) were selected. The figures reported below with regards to costs per hectare reflect only the contracting costs.

The number of needed follow-up treatments is an important contributing factor to the cost of clearing. As an example, Fig. 2

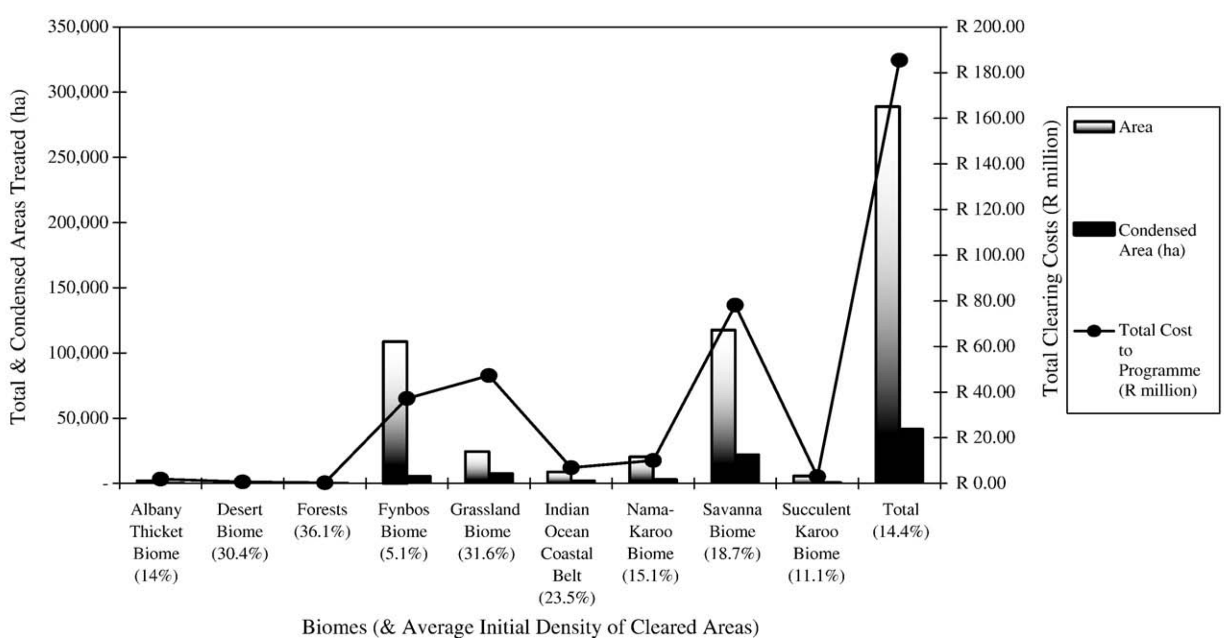

Fig. 5. Clearing costs in relation to area treated for different biomes.

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Table 3
Estimated impact of clearing species known for high water use on invasion estimates[a]

Water management area	Area treated (ha)	Total condensed area (ha)	Estimated extent of riparian invasions (ha)[a]	Estimated extent of riparian invasions condensed area (ha)[a]	% of area treated	% of condensed area treated
Limpopo	1073	425	36,560	9269	3%	5%
Luvubu–Letaba	323	35	18,631	1418	2%	2%
Crocodile West and Groot Marico	4854	1599	32,137	8148	15%	20%
Olifants	2775	840	49,512	24,946	6%	3%
Inkomati	6447	2213	26,531	6726	24%	33%
Usutu–Mhlathuze	2404	927	54,918	27,670	4%	3%
Thukela	3308	541	34,476	17,371	10%	3%
Upper Vaal	613	203	59,880	15,181	1%	1%
Middle Vaal	–	–	31,935	2430	0%	0%
Lower Vaal	5304	1613	31,935	2430	17%	66%
Mvoti–Umzimkulu	4088	1628	97,424	49,087	4%	3%
Mzimvubu–Keiskamma	1734	1228	40,066	20,187	4%	6%
Upper Orange	545	263	65,295	4969	1%	5%
Lower Orange	6621	2386	86,330	4969	8%	48%
Fish–Tsitsikamma	3420	756	81,916	41,273	4%	2%
Gouritz	17,788	1632	44,804	11,359	40%	14%
Olifants–Doorn	48,452	1213	35,000	2663	138%	46%
Breede	28,355	1320	16,458	8292	172%	16%
Berg	7688	796	8967	4518	86%	18%
Total	145,793	19,619	852,777	262,907	17%	7%

[a]Estimates by Cullis et al. (2007).

shows the decline in number of entries in the database of successive follow-up treatments for *Acacia*. This represents the rate at which polygons are handed over to the land user for maintenance (exited the programme). For a closed stand (75–100%), the number of entries declines from more than 800 to less than 700 at the first follow-up and to around 450 at the second follow-up. From there, it drops to just more than a quarter of the original number of entries, and to 15% of initial entries after the fourth treatment.

Fig. 3(a–d) shows the average treatment costs for the different densities of *Acacia, Chromoleana, Eucalyptus* and *Pinus spp.* based on the area initially treated. For large-scale planning and socio-economic assessments in relation to costs, workload is important (person days of work per hectare). Table 2 is a summary of the initial and follow-up costs and workload for *Acacia, Chromoleana, Eucalyptus* and *Pinus* species for the 75–100% and 1–5% densities respectively. As can be seen from Fig. 4 (a subset of Fig. 3(a)), some polygons are being treated for up to eight times at significant costs. For such polygons, the total contracting costs on average goes up to *R*8600 per hectare (approximately *R*3240 initial and *R*5370 for all follow-ups for a 75–100% invasion).

Because of tree size, one would expect *Eucalyptus* clearing costs to be in line with, if not more than, that of *Acacia*. However the results show that, according to available data, this is not the case (Table 2; Fig. 3(c)). This unexpected result may

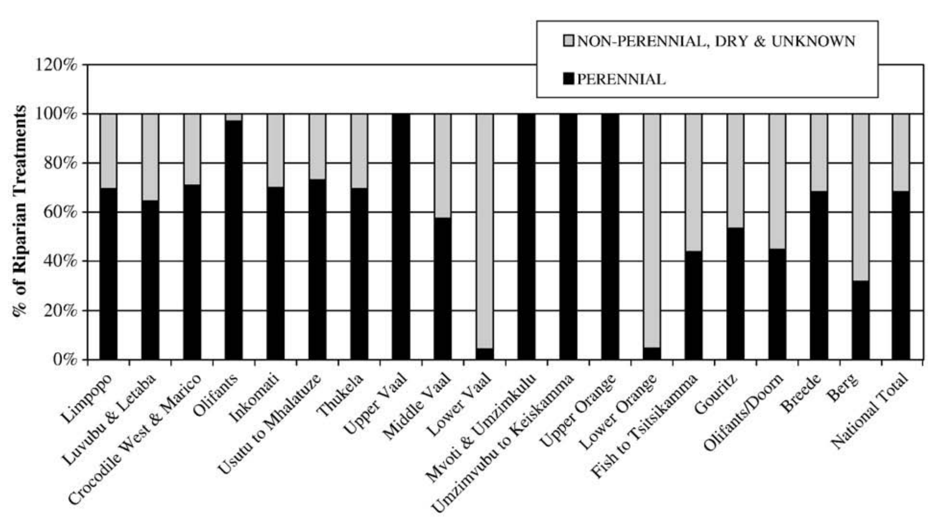

Fig. 6. Distribution of riparian treatments (using river lengths) between perennial and non-perennial rivers.

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Table 4
Raw water tariffs, clearing unit reference values (URV)[a] and net present values (NPV) of clearing operations

Water catchment area	Raw water tariff	Unit reference value			Net present value		
		Discount rate			Discount rate		
		4%	6%	8%	4%	6%	8%
Limpopo (1)	*R*0.08	*R*1.96	*R*2.47	*R*3.01	*R*1,241,193	*R*925,851	*R*725,330
Luvuvhu and Letaba (2)	*R*0.05	*R*12.45	*R*15.68	*R*19.08	*R*56,704	*R*42,297	*R*33,137
Croc West–Groot Marico (3)	*R*0.08	*R*4.08	*R*5.14	*R*6.26	*R*4,725,547	*R*3,524,958	*R*2,761,521
Olifants (4)	*R*0.30	*R*0.75	*R*0.94	*R*1.14	*R*11,665,296	*R*8,701,569	*R*6,816,979
Inkomati (5)	*R*0.06	*R*3.38	*R*4.25	*R*5.18	*R*4,958,350	*R*3,698,614	*R*2,897,566
Usutu–Mhlatuze (6)	*R*0.16	*R*0.72	*R*0.91	*R*1.10	*R*5,782,046	*R*4,313,039	*R*3,378,919
Thukela (7)	*R*0.14	*R*1.00	*R*1.26	*R*1.53	*R*2,744,934	*R*2,047,546	*R*1,604,088
Upper Vaal (8)	*R*0.91	*R*0.21	*R*0.26	*R*0.32	*R*8,635,950	*R*6,441,870	*R*5,046,687
Middle Vaal (9)	*R*0.12	*R*0.00					
Lower Vaal (10)	*R*0.06	*R*5.24	*R*6.60	*R*8.04	*R*1,529,123	*R*1,140,628	*R*893,591
Mvoti–Umzimkulu (11)	*R*0.17	*R*0.69	*R*0.87	*R*1.06	*R*12,812,135	*R*9,557,038	*R*7,487,171
Mzimvubu–Keiskamma	*R*0.29	*R*0.39	*R*0.49	*R*0.59	*R*16,881,488	*R*12,592,517	*R*9,865,224
Upper Orange (13)	*R*0.05	*R*2.02	*R*2.55	*R*3.10	*R*648,865	*R*484,012	*R*379,185
Lower Orange (14)	*R*0.04	*R*4.40	*R*5.54	*R*6.75	*R*1,770,815	*R*1,320,915	*R*1,034,831
Fish–Tsitsikamma (15)	*R*0.06	*R*6.16	*R*7.76	*R*9.44	*R*1,330,581	*R*992,529	*R*777,567
Gouritz (16)	*R*0.04	*R*4.03	*R*5.08	*R*6.18	*R*2,258,324	*R*1,684,566	*R*1,319,722
Olifants–Doorn (17)	*R*0.01	*R*20.25	*R*25.51	*R*31.05	*R*451,251	*R*336,604	*R*263,703
Breede (18)	*R*0.03	*R*7.64	*R*9.62	*R*11.70	*R*1,371,975	*R*1,023,406	*R*801,757
Berg (19)	*R*0.10	*R*4.87	*R*6.13	*R*7.46	*R*1,971,497	*R*1,470,612	*R*1,152,106
National Weighed URV & NPV	*R*0.12	*R*1.64	*R*2.07	*R*2.52	*R*85,270,875	*R*63,606,651	*R*49,830,696

[a]See Section 2.5.

relate to the fact that the clearing of mature stands of *Eucalyptus* is so expensive that the regions have steered away from clearing them. Further work is needed on clearing costs and workload of *Eucalyptus*.

Non-sprouting species such as *Pinus* (Fig. 3(d)) tend to be less expensive to clear than sprouters such as the majority of *Acacia* species. Note also the low number of follow-up treatments in comparison to that of the other genera.

3.3. Invasive alien plants clearing per biome

On the surface, it seems that expenditure per biome is in proportion with the areas treated, except for the Fynbos and Grassland Biomes (Fig. 5). However, when one compares the weighted average density of areas treated it becomes clear that the average density of areas treated in the Fynbos Biome is significantly lower than that of the other biomes (5% versus an average of 14.4%). By contrast, the average condensed area treated in the Grassland Biome is 31.6%. The reason for the expenditure being in line with the condensed area treated in the Forests (average density 36.1%) and the Desert Biomes (average density 30.4%) could possibly be ascribed to the species that tend to invade these areas. As will be seen later, densities do have an impact on the cost of generating extra yield. The denser the stand, the bigger the increase in yield and therefore return on investment if future losses due to

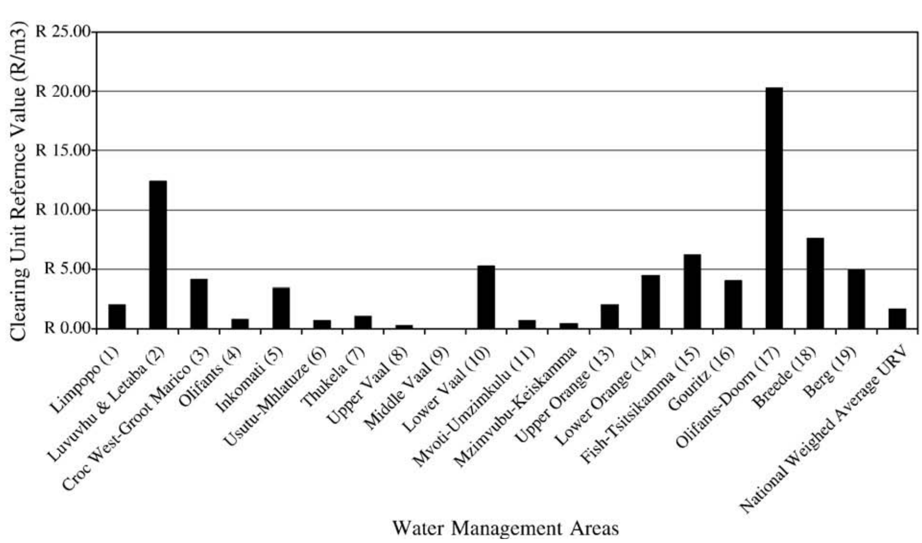

Fig. 7. The clearing unit reference values of clearing invasive alien plant plants known for high water using from riparian areas in South Africa (@ 4% discount rate).

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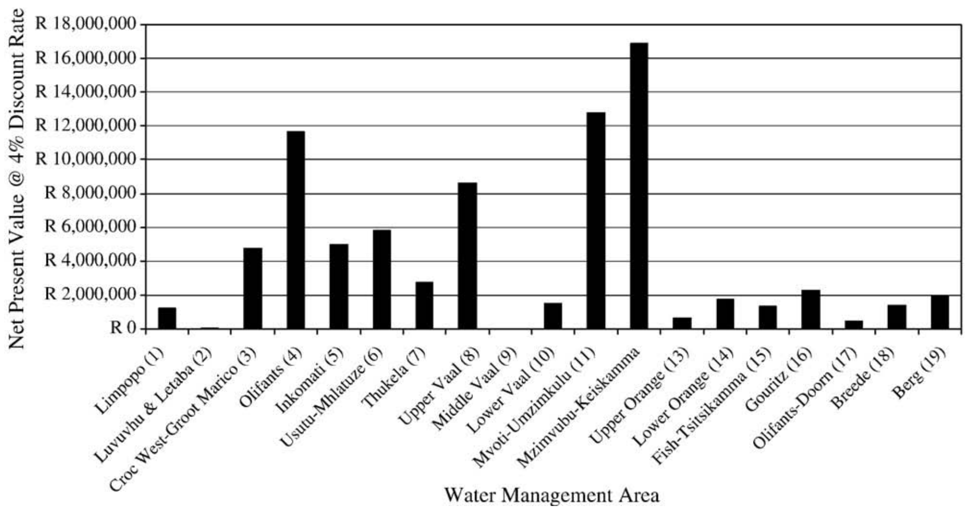

Fig. 8. Net present value of clearing invasive alien plants known for high water use from riparian areas in South Africa (@ 4% discount rate).

increased alien densities and clearing costs are not taken into account.

3.4. Impact on water yield

Some 19,600 condensed hectares of high water use species have been cleared from riparian areas during the period from September 1998–August 2006 (Table 3) at a clearing contract cost of nearly *R*87 million. Using the results from the assessment of clearing in perennial and non-perennial rivers (Fig. 6), and the assumptions used by Cullis et al. (2007), it is estimated that the clearing led to a stream flow increase of nearly 46 million m^3 per annum and an increased yield of 34.4 million m^3 per annum (including major and minor dams and run of river extraction). This represents 6.6% of the 523 million m^3 estimated losses from riparian areas due to invasive alien plants, and 5% of the 695 million m^3 lost to both riparian and mountain catchment area invasions. To compare the viability of clearing in the different water management areas, a *clearing unit reference value* was used, as explained in Section 2.5. Table 4 shows the estimated clearing unit reference value and the net present value of species known for excessive water use in riparian areas in the 19 Water Management Areas of South Africa. These results can be used in preliminary assessments, to test the viability of clearing invasive alien plants in terms of increased yields in the respective Water Management Areas and therefore in the prioritization of clearing operations. These results can only be used to assess the viability of clearing in terms of immediate increases in yield. They do not take into account future losses (impacts on future water security) if invasions are left unchecked.

Fig. 7 shows the clearing unit reference value for the respective water management areas as well as the national weighted average, while Fig. 8 shows the net present value of riparian clearing per Water Management Area. The total net present value for the country is more than *R*80 million. It is important to note the exceptionally high clearing unit reference values of some Water Management Areas e.g. Olifants–Doorn, Breede and Luvuvhu & Letaba catchments. A high unit reference value would make invasive alien plant clearing a less competitive option against other augmentation options. However, the overall unit reference value of *R*1.52 is very competitive.

4. Discussion

As found by Marais et al. (2004), Australian *Acacia* is the genus on which the most money is being spent, with good reason, as all earlier studies found the extent of Australian *Acacia* to be higher than any other genus. The results again confirm the impact of density on clearing costs: the longer one waits with the clearing of invasive alien plants, the more expensive it becomes. More work is still needed on the costs and workload of *Eucalyptus* in order to get improved estimates for this genus. If assessed in terms of increased yield, one could conclude that the return on investment is higher when denser stands are being cleared. The findings of this paper do not address the potential future impact of dense stands of invasive alien plants on water security or the opportunity cost of waiting until an area is densely invaded. Not only does the impact increase but also the cost of clearing. Costs of clearing very scattered invasions in comparison with dense stands are between 3 and 20 times cheaper.

There are relatively high clearing unit reference values for the Water Management Areas in the Fynbos Biome where the average initial densities are 5% versus the 14% national average. This means that the relative clearing cost per condensed hectare for low levels of infestation is higher than that of denser stands. The cost per condensed hectare of *Acacia* at 1–5% for example is nearly *R*9000 while that for a 75–100% stand is less than *R*4000. It is expected, therefore, that the clearing unit reference value for the Fynbos Biome will be higher than the denser invasions in the other biomes. The low average clearing densities for the Fynbos Biome can most probably be ascribed to the fact that a significant percentage of the clearing takes place within the declared mountain catchment areas (Mountain Catchment Areas Act of 1970) and state forests. Furthermore tree invasions in the grassland, savanna and karoo biomes tend to be more aggressive in riparian areas than in uplands, while in the Fynbos *Pinus* aggressively invades upland areas as well. During the 1970s and early 1980s, a very successful clearing programme was implemented by the then Department of Forestry in the latter areas. This has led to invasive alien plants being largely under control in much of the mountain catchment areas by the late 1980s. There were serious cutbacks in funding, however, from the mid 1980's until the inception of the Working for Water programme in 1995.

There are clearly some cases where actively restoring indigenous vegetation cover should be considered to reduce the costs of follow-up clearing. As a preliminary assessment, one can assume that if the total clearing cost is more than *R*8000 per hectare and the follow-up costs is more than *R*4000, then the situation warrants restoration interventions. Preliminary estimates of restoration costs are between *R*3000 and *R*6000 per hectare (Holmes et al., 2007; Mills et al., 2007). If one then compares the above costs to the average initial clearing cost of *R*1200 for *Pinus spp.* and *R*2200 for *Acacia spp.* there will be some cases when it is worth the while to invest in restoration in order to reduce the need for follow-up. For *Acacia,* this means that 106 ha out of 3519 or 3% of area treated with an initial density of 75–100% should be considered for restoration. For the 50–75% class, only 27 out of 4536 ha or less than 1% should be considered for restoration. These areas might seem small but one should not forget that this only represents riparian clearing and only *Acacia* is being considered.

Despite the relatively small areas of *Eucalyptus* treated, the outcome of a similar assessment is very different to that of *Acacia*. If the same criteria as above are applied, of the 747 ha of 75–100% stands, 485 or 65% will need to be considered for restoration. For 50–75% density, 620 ha or 49% of the 1259 ha treated will have to be considered. This is a very significant percentage. Further work is needed, therefore, to get a better estimate of the total demand for restoration in the programme. There is preliminary evidence that the successful establishment of indigenous vegetation can suppress alien recruitment (Pretorius et al., 2008-this issue). Furthermore, it is clear that sprouting invasive trees (*Acacia* and *Eucalyptus*) are more expensive to clear (with high workloads) than shrubs like *Chromoleana*, while non-sprouting species such as *Pinus* tend to be less expensive (with lower workloads). Where biocontrol is a management option, it must be considered but in the short-term, biocontrol in most cases simply reduces the rate of spread, rather than reducing the total extent of the invasion, especially in the case of commercial genera such as *Acacia*, *Eucalyptus* and *Pinus*. What is also important to take into account is the fact that the impacts of these species on natural resources, especially on water resources, and ecosystem processes are believed to be more severe than in the case of shrubby species.

Larson et al. (2001) have shown that if invasions in the catchments of George in the Western Cape are left unchecked it could have significant impacts on the cost of augmentation options. Cullis et al. (2007) estimated that as much as 16.1% of the country's water yield can be lost if invasive plants in the mountain catchments and riparian areas are left unchecked. Further work is needed to assess the value of early detection and rapid response to alien plant invasions.

The results of this paper, in terms of the viability of clearing riparian areas to improve water resource management, are being expressed as the increased yield after clearing. The URVs for some of the Water Management Areas are very high; for example, the Luvuvhu–Letaba and Olifants–Doorn areas. This result does not address the future impacts of increased extent of riparian invasions on yield, nor does it take into account the increased costs of clearing denser stands. Table 2 clearly shows the effect of a no-intervention approach versus an approach of clearing invasions as soon as possible. Cullis et al. (2007) concluded that potential yield losses could increase, from the current 4% to more than 16% of registered water use, if invasive alien plants in mountain catchments and riparian areas are left unchecked. This paper should be followed up by looking at the value of (current) clearing in terms of future water losses. It is expected that the URVs of such an assessment will differ significantly from the results of this paper. Such a paper should also look at an improved estimate of the value of water, rather than using the raw water tariff as we've used in this one.

There are still a number of shortcomings in our estimates of riparian invasions and their potential impacts. For instance, areas treated in the Breede, Berg and Olifants–Doorn are 172%, 86% and 138% of the extent of invasions as estimated by Cullis et al. (2007). This can possibly be ascribed to the fact that all polygons that overlaid rivers were assumed to be riparian area for the purposes of this study. Large polygons with low densities were treated in the mountain catchments of the Western Cape. The polygons could therefore be expected to extend beyond the riparian zones. Most of these polygons are in mountain catchments (high rainfall areas), where the impacts could be assumed to be relatively similar to riparian areas. Overall, it is estimated that around 7% of riparian invasions have been cleared. The estimated increase in yield from this clearing is highly significant. The increased estimated yield of 34.4 million m^3/year is about 42% of the yield of the new Berg River Scheme (81 million m^3/year) in the Western Cape which was developed at a cost of around *R*1.6 billion. The investment in clearing species known for excessive water use from riparian areas at a cost of *R*116 million, therefore is a very good investment. It is important to note that the clearing of invasive alien plants will seldom result in the total elimination of water supply shortfalls but should be seen as part of a package of water resource options to optimize supply.

Finally, the clearing in riparian areas is well distributed across the different biomes. The costs per biome in relation to the condensed hectares indicate that the nature of invasions varies amongst the different biomes. For example, clearing in the Fynbos and Grassland Biomes tend to be more expensive per condensed hectare than in other biomes. The implications of this should be investigated further in order to assess the clearing strategies used in the respective biomes.

The results of this study can be used in two ways. Operational staff can use the clearing costs for local planning purposes as presented in Figs. 2–4, provided that the costs of chemicals are added. For socio-economic assessments and strategic scale planning, total costs need to be used as is done with the calculation of the clearing unit reference value and net present value in this study.

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