An assessment of the effectiveness of a large, national-scale invasive alien plant control strategy in South Africa

Brian W. van Wilgen[a*], Greg G. Forsyth[a], David C. Le Maitre[a], Andrew Wannenburgh[b], Johan D.F. Kotzé[c], Elna van den Berg[c] and Lesley Henderson[d]

[a]Centre for Invasion Biology, CSIR Natural Resources and the Environment, P.O. Box 320, Stellenbosch, 7599, South Africa; [b]National Working for Water Program, Department of Environmental Affairs, Private Bag X4390, Cape Town 8000, South Africa; [c]Institute for Soil, Climate and Water, Agricultural Research Council, Private Bag X79, Pretoria, 0001, South Africa; [d]Plant Protection Research Institute, Agricultural Research Council, c/o SANBI, Private Bag X101, 0001 Pretoria, South Africa.

* Corresponding author: Tel: +27 21 888 2400; Fax: +27 21 888 2693

Email address: bvwilgen@csir.co.za (B.W. van Wilgen).

ABSTRACT

This paper presents an assessment of a large, national-scale alien plant control program that has operated in South Africa for 15 years. We reviewed data from three national-level estimates of the extent of invasion, records of the costs and spatial extent of invasive species control operations, assessments of the effectiveness of biological control, and smaller-scale studies. We identified the most important invasive species in terrestrial biomes, and assessed how control efforts have impacted on the extent of invasion of these species. We focussed on 18 alien taxa, mainly trees, that were prominent invaders. Control costs over 15 years amounted to US$457 million, almost half of which was spent on 10 taxa, the most prominent being invasive trees in the genera *Acacia*, *Prosopis*, *Pinus* and *Eucalyptus*. Despite significant spending, control operations were in many cases applied to a relatively small proportion of the estimated invaded area, and invasions appear to have increased in many biomes, where they remain a serious threat. Our findings suggest that South Africa's national-scale strategy to clear invasive alien plants should be substantially modified if impacts are to be effectively mitigated. Rather than attempting to control all species, and to operate in all areas, a more focused approach is called for. This would include prioritizing both species and areas, and setting goals and monitoring the degree to which they are achieved, within a framework of adaptive management. A greater proportion of funding should also be directed towards biological control, where the most notable successes have been achieved.

Keywords: Adaptive management, biological control, biological invasions, ecosystem services, invasive alien species, Working for Water

1. Introduction

Alien plant invasions are a large and growing threat to ecosystem integrity in many parts of the world, where they change the structure and functioning of ecosystems, with negative consequences for the conservation of biodiversity and the delivery of ecosystem services (Mooney 2005). There are several examples of high-level strategies to deal with the problem of invasive alien species, both at global (McNeely et al. 2001) and national levels (Federal Interagency Committee 1998; Anon. 1999). These strategies all call for reducing the risk of new introductions of invasive species, the control of existing invasions to mitigate impact, and the establishment of management and legislative capacity to guide implementation. Interventions that give effect to national strategies are often a major component of the management of terrestrial ecosystems (Wittenburg and Cock 2005), and attempts to control invasive species can and have brought about significant levels of mitigation (Simberloff *et al*. 2011).

In South Africa, the strategy over the past 15 years has been to implement a large, national-scale, government-sponsored alien plant control program (van Wilgen *et al*. 1998; 2011a; Koenig 2009). Known as 'Working for Water', the program has adopted a comprehensive approach to alien plant control, characterised by several distinguishing features. The program combines mechanical and chemical control of all invasive alien plant species in targeted areas with the provision of employment to people from impoverished rural communities as its main thrust. This has been supplemented by (1) the development of biological control options that target selected priority alien plant species (Zimmermann *et al*. 2004; Moran *et al*. 2005); (2) the promulgation of legislation that requires landowners to deal with the problem (van Wilgen *et al*. 2011a); and (3) the encouragement of systems of payment for ecosystem services that will generate funding to support control programs (Turpie *et al*. 2008). Few countries have implemented similar control programs, and we are not aware of any that have assessed their effectiveness at a national scale over one and a half decades.

When Working for Water was initiated in 1995, an attempt was made to quantify the extent of invasions at a national scale (Versfeld et al. 1998), to provide inputs for management planning (see, for example, Le Maitre et al. 2002), to assist in the quantification of impacts (Le Maitre et al. 2000), and to serve as a baseline against which to assess trends. Working for Water has since spent 3.20 billion rands (expressed as 2008 rands, approximately 457 million US$) on alien plant control. Whether or not the correct, top-priority, species are being targeted, and whether or not progress has been made in reducing the extent of invasions, remains unknown. While Working for Water has kept records of expenditure per species and geographic area since 2002, the ability to address questions regarding the effectiveness of their operations is limited because the program has not implemented an effective system of monitoring and evaluation (Levendal et al. 2008). A preliminary assessment of progress (Marais et al. 2004) was made by comparing the rate of clearing to the rough approximations of invaded area in 1996. Marais et al. concluded that, at the prevailing rates of clearing, and depending on the species, it would take between two and 83 years to clear the most important species, but with the important albeit unrealistic assumption that no further spread would take place during this time.

Working for Water has taken several steps to assess trends and changes in the situation. These include the commissioning in 2008 of a second national-scale assessment of the extent of invasion (Kotzé et al. 2010), providing ongoing financial support to a national-scale atlas project (Henderson 2007), and supporting (or acting as a catalyst for) several finer-scale research projects. The study reported in this paper used information from all of the above sources to assess the effectiveness of Working for Water in suppressing and controlling invasive alien plants in South Africa, and we propose improvements that could increase efficacy and success.

2. Methods

2.1 Studies by biome

Working for Water is a national-level initiative in South Africa, operating in all nine of the country's provinces and across all major terrestrial biomes. The country's indigenous vegetation is diverse, including nine terrestrial biomes, and high levels of endemism are a feature of several biomes (Mucina and Rutherford 2006). We used biomes as a basis for our assessment, as each biome is characterised by particular features (e.g. fire and rainfall regimes, and levels of herbivory), and is invaded by distinctive suites of alien plant species (Table 1). Much of the natural vegetation remains untransformed, and provides important ecosystem services in the form of livestock production from rangelands, water production from mountain catchments, and conservation and tourism benefits from protected and other areas. All of these services are under considerable threat from invasive alien plants (van Wilgen et al. 2008a).

2.2 Extent of invasions

There have been three national-scale, and several smaller-scale, estimates of the extent of alien plant invasion in South Africa, compiled over the past 15 years. We used these estimates to identify the most important species involved and to assess, within the limits of the data (see section 2.6) the extent to which they have impacted on the terrestrial biomes of South Africa.

The first estimate was initiated in 1994 by the Southern African Plant Invaders Atlas (SAPIA, Henderson 1998). SAPIA is an ongoing project, which aims to collate information on the distribution and abundance of invasive and naturalized alien plants in southern Africa. Initially, the atlas was populated with data collected during roadside surveys, but was later broadened to accept inputs from volunteers, who were supplied with survey sheets to ensure the standardization of inputs. By 2006, the SAPIA database contained approximately 58 000 records of alien plant species presence and abundance within quarter degree squares (a grid of approximately 25 x 25 km). Henderson (2007) used the SAPIA database to estimate a prominence value for each species, calculated as $P_i = A_i/A + R_i/R$ where P_i = the prominence of species *i* in a particular area, A_i = the abundance of species *i*, A = the abundance of all species, R_i = the total number of records of species *i* and R = the total number of records of all species.

The second estimate was made in 1996 (Versfeld et al. 1998; Le Maitre *et al*. 2000). Data on the extent and location of the areas invaded by all important invasive alien plant taxa were obtained from a variety of sources for this survey, including some detailed field mapping, mainly at a 1:250 000 scale, with some at 1:50 000 and at 1:10 000. The species data were captured, together with estimates of their density for each of the mapped areas, in a GIS database. The density class of each species in each polygon was used to estimate condensed areas (the equivalent area with a canopy cover of 100%). The authors of the survey noted that the findings were rough approximations, and needed to be interpreted with caution because the results were based on a data set that contained some important uncertainties.

A third estimate in 2008 mapped 27 alien plant taxa (Kotzé *et al*. 2010). Species in the genera *Pinus* and *Eucalyptus* and some *Acacia* were mapped collectively. Prior to the survey, the entire country (excluding most of the arid biomes - Desert, Nama karoo, succulent karoo, and arid portions of the grassland and savanna biomes - and the Kruger National Park) was divided into homogenous environmental units (HEUs), based on unique combinations of three classes of rainfall, soil depth, clay content in the B-horizon of the soil, and two classes of terrain in each tertiary (3rd order) catchment. Those portions of HEUs that had been transformed were excluded. The remaining portions of the HEUs were then sampled at 32 330 points. Points were allocated to HEUs in proportion to their area, and then located at random within HEUs. At each sample point, the percentage cover of the three dominant alien plant taxa was estimated from low-flying fixed-wing light aircraft or helicopters on 100 x 100m plots by observers who were familiar with invasive species in the area. A second set of 25 260 sample points were located on a grid of 1600 x 1600m in a subsample of 205 quaternary (4^{th} order) catchments (about 10% of the country), and results from this survey were used to verify broad levels of invasion detected in the national survey. Survey data were used to estimate mean percentage cover and coefficient of variation for each of the taxa in each HEU in each catchment. We converted these estimates to 100% equivalent cover ("condensed ha") for comparison to other surveys, using the formula C = d/100 x A, where C is the area expressed as condensed ha, d is the density (% cover), and A is the area in ha that was treated.

We obtained estimates of the extent of invasion per biome by creating subsets of the spatial databases described above using Mucina and Rutherford's

(2006) biome boundaries. In the case of the SAPIA database, a biome-scale analysis of the data was already available (Henderson 2007). Our analysis excluded the arid portions of the grassland and savanna biomes, which were not covered by Kotzé et al.'s (2010) survey. A recent estimate of the extent of invasion by *Prosopis* species was available for the Northern Cape Province (which includes large portions of the succulent karoo, Nama karoo, arid grasslands and arid savannas) (van den Berg 2010). Control in these biomes has focussed almost entirely on *Prosopis* species, so we restricted our assessment in these biomes to the clearing of *Prosopis* species in the Northern Cape Province. A number of finer-scale studies were used to provide insights into trends in the extent of invasion in South Africa, and into the effectiveness of control operations. These included Esler *et al*. (2010) for *Hakea* species in the fynbos biome, Moeller (2010) for *Pinus* species in the Eastern Cape Province, and Otten (2010) for *Acacia cyclops* in the Western Cape Province.

2.3 Selection of invasive alien plant taxa

We focussed our assessment on the most important invasive alien plant taxa. These taxa were defined as the top 10 in terms of area occupied in the estimates of Le Maitre et al. (2000) and Kotzé *et al*. (2010), and the top 10 in terms of prominence value as defined by Henderson (2007, see section 2.2). In addition, we ranked taxa in each biome in terms of the cost of control, and included the highest-ranked taxa that jointly accounted for at least 85% of control costs in any given biome. Authorities for species names, and common names, are provided in Tables 1 and 2, or at first mention in the text for species not in Tables 1 or 2.

2.4 Costs of control

The costs of control have been recorded by Working for Water in a spatially-explicit database since 2002 (Marais *et al*. 2004). All of Working for Water's control operations are carried out by contractors. The records include the species treated and the direct costs paid out to contractors. As the records do not contain Working for Water's overheads, we assumed that overhead costs (funds spent by Working for Water minus funds paid to contractors for each year) were distributed among taxa in the same proportion as the expenditure on the control of individual taxa. The costs of chemicals were not recorded in the contractor database, and we included these in overheads. We further assumed that funds expended prior to 2002 (1995 – 2001) were allocated to the control of individual species in the same proportions as funds expended after 2002. Finally, we used the consumer price index to inflate all costs to 2008 rands to account for inflation (1 US$ = approximately 7 South African rands). We used 2008 as a base year to allow for direct comparisons between expenditure and the estimates of invasion up to that year.

2.5 Extent of control

Working for Water's contractor database contains the following records for each site: the species being treated, the area treated (captured spatially at a scale of at least 1:15 000), and the density of the infestation (based on aerial canopy cover). For each biome, we determined the area that had been treated for each of the selected invasive alien plant taxa (including initial treatment, and all follow-up treatments where applicable). Areas were expressed as equivalent to 100% canopy cover ("condensed ha") using the formula C = d/100 x A, where C is the area expressed as condensed ha, d is the density (% cover), and A is the area in ha that was treated.

2.6 Trends in alien plant cover

It is important to understand trends in alien plant cover to assess whether control efforts are sufficient to stem the spread or reduce the degree of invasion by alien plants or, if insufficient, to estimate the control effort that would be needed to bring the species under control. Ideally, this should be done by comparing the degree of invasion over time in successive estimates that use the same approach. However, in our study, such direct comparisons were not possible because of the different approaches used in making the estimates. We therefore assessed trends for the most important alien plant species using estimates from the two national surveys (Le Maitre et al. 2000 and Kotzé et al. 2010) and the estimates of extent of control, as indicators and not as comparable estimates. The emergence of new, rapidly-spreading invasive species was assessed using the rate of addition of records to the SAPIA database. In addition post-release monitoring of biological control agents provided further insights into the effectiveness of control (Klein 2011; Moran and Hoffmann 2011).

3. Results

3.1 Extent of invasions and prominent taxa

Invasive alien plants were estimated to occupy approximately 1.736 million condensed ha in 1996 (Le Maitre 2000). By combining the estimates of Kotzé et al. (2010) and van den Berg (2010) (which are from mutually exclusive areas that together cover most of the country), the estimated extent of invasion in 2008 was approximately 1.813 million condensed ha. While these estimates are not directly comparable (section 2.6) the similarity of the estimates suggest that invasions have not decreased. Records in the SAPIA database indicate that alien plant invasions occur throughout South Africa, but are concentrated in the southwestern, southern and eastern coastal belts and the adjacent interior, which are also the areas of highest rainfall (Henderson 2007).

We focussed on 18 invasive alien plant taxa in this assessment (Table 2). Of these, 15 were identified by merging the lists of the 10 most important taxa in either Le Maitre et al. (2000), Henderson (2007) or Kotzé et al. (2010). A further three were added because, despite their lower prominence, they were targeted for clearing and attracted a significant proportion of clearing costs in at least one biome. These were *Acacia melanoxylon*, *Cereus jamacaru* and *Caesalpinia decapetala*, targeted for control in forest habitats, moist savannas and the Indian Ocean coastal belt respectively. Almost all prominent taxa (15) were either trees or shrubs (Table 2).

3.2 Costs of control

The costs of control by Working for Water between its inception in 1995 and the end of 2008 amounted to 3.20 billion rands (expressed as 2008 rands). Most (83%) of the funds were spent on the top 10 taxa, with the remainder divided among 95 less prominent taxa. The largest proportion of funding (1.05 billion rands) was spent on the control of *Acacia mearnsii*. If this is added to the costs associated with the closely-related wattle species *Acacia dealbata* (cost of 86.9 million rands), the costs of control of these two species accounted for more than one third of the costs of all alien plant control. A total of 323.3 million rands was spent on the next most-targeted taxon (*Prosopis* species), while 290.5 and 214.1 million rands were spent on *Pinus* and *Eucalyptus* species respectively. The remaining taxa in the top 10 (and costs of control in millions of rands) were *Chromolaena odorata* (207.5), *Cereus jamacaru* (155.5), *Lantana camara* (153.5), *Hakea* species (95.2) and *Solanum* *maurtitianum* (69.4). The number and identity of the taxa attracting the highest clearing costs varied in the different biomes (Table 3).

3.3 Assessment of control achieved in biomes

3.3.1 Fynbos biome

Control efforts may have reduced the extent of invasion of some, but not all, of the species selected for our assessment in the fynbos biome. A relatively small proportion (12.6 and 9.6%) of the 2008 estimated extent of *Acacia cyclops* and *A. saligna* respectively have been subjected to control treatments (Table 3), but the species may have declined in abundance as a result of the combined effects of significant but unrecorded clearing by firewood cutters (not accounted for in Working for Water's records) and a substantial degree of biological control (Table 4; see also Otten 2010). Similarly, there are indications that *Hakea* species have declined because of historic (pre-1995) mechanical clearing, ongoing clearing by Working for Water, and a substantial degree of biological control (Esler et al. 2010). Both *Acacia longifolia* (Andr.) Willd. (long-leaved wattle) and *A. saligna* and were previously considered to be among the five most important invasive plant species in the biome (Macdonald and Jarman 1984). The extensive monocultures of large, 8-m tall *A. saligna* trees that previously dominated lowland fynbos areas have almost completely disappeared as a result of biological control using a rust pathogen, and the species survives only as patchy, but still problematic, clusters of diseased shrubs (Moran and Hoffmann in 2011). In the case of *A. longifolia*, biological control has reduced the relative importance of the weed to no more than "an incidental or trivial problem" (Moran and Hoffmann 2011).

On the other hand, there is no indication that the extent of invasion by either *Acacia mearnsii* or *Pinus* species has decreased in the fynbos biome, despite significant spending on the problem~~areas having been treated~~. About 70% and 60% of the estimated area of *A. mearnsii* and of *Pinus* in 1996 respectively had been treated between 2002 and 2008 (and more before records began), yet these species remain prominent. One study in the eastern fynbos biome (Moeller 2010) estimated that the cover of invasive *Pinus* had more than doubled (from 13.4 to 28.7%) between 1986 and 2007. Gains made in the control of *Hakea* species are being offset by invasion by *Pinus* species, which are equally successful invaders of the same areas. Biological control may become more effective in future as the agents on *Acacia mearnsii* spread and deplete seed loads, but no such solution is available for *Pinus* (Table 4). In particular, the rugged and inaccessible mountain areas are most vulnerable to invasion by *Pinus* species, and this poses the most significant threat to the integrity of fynbos ecosystems (Hoffmann et al. 2011; Kraaij et al. 2011).

Comment [U@1]: Treatment has been localised, only 4% of Versfeld "extent"

3.3.2 Grassland biome

Most of the control effort in grassland has been focussed on two tree taxa (*Acacia* and *Eucalyptus* species, Table 3). About 20% of the 2008 estimated area of the *Acacia* invasions has been subjected to control, compared to a very small proportion (3.4%) of the *Eucalyptus* species. There appears to be no detectable decline in the estimated extent of invasion by *Acacia* species between 1996 and 2008, suggesting that control operations are may not be keeping pace with invasion rates. Both *Salix babylonica* and *Populus* species (prominent invaders of riparian zones) received hardly any control, and appear to have increased. In addition, the grassland biome is vulnerable to invasion from non-woody plants. These were not included in our assessment as they have not been subjected to any significant degree of control. For example, several species in the genus *Rubus* (thorny shrubs), and the herbaceous *Cirsium vulgare* (Savi) Ten. (Scotch thistle) are prominent invaders of grasslands (Henderson 2007). In addition, the perennial herb *Campuloclinium macrocephalum* (Less.) D.C. (pompom weed) has recently undergone spectacular expansion in grasslands. Records from the SAPIA database show that it spread from 48 to 93 quarter degree squares between 2005 and 2010. Grasslands thus remain under significant threat from invasions despite considerable clearing efforts.

3.3.3 Savanna biome

Alien plant control efforts in the savanna biome were focussed on more taxa than other biomes (Table 3). Species of Cactaceae (including *Cereus jamacaru*) appear to have declined (Table 3), but much of this may be due to biological control rather than mechanical clearing. Despite spending over 444 million rands on the remaining prominent taxa, it was only possible to treat a relatively small proportion (4.3 – 38%) of their estimated 2008 invasions. The exception was *Lantana camara*, where 88% of the 2008 estimated area was treated, and the extent of invasion may have declined. For other species, notably *Acacia mearnsii* and *Chromolaena odorata*, large increases between the 1996 and 2008 estimates of invaded area suggest that the extent of invasion may have increased in spite of control efforts. New invaders are also emerging in savannas, including *Tecoma stans* (L.) Kunth. (yellow bells), an ornamental shrub or small tree, that has more than tripled its extent from 28 known quarter degree squares in 1996 to 86 quarter degree squares in 2011.

3.3.4 Forest biome

Alien plant control operations in the forest biome focussed on trees in the genera *Acacia*, *Eucalyptus* and *Pinus* (Table 3). Forests only cover 0.38% of South Africa (Table 1), with a scattered distribution. The scale of mapping used in various surveys is relatively coarse compared to the distribution of forests, and it is therefore not possible to draw confident conclusions regarding the success of control operations in the forest biome.

3.3.5 Albany thicket biome

Alien plant control operations in the thicket biome focussed on a single species (*Acacia mearnsii*), which accounted for > 85% of the control costs. The estimates of the invaded area in 1996 and 2008 suggest that invasions may have increased. Such an increase would not be surprising, given that only a small proportion of the estimated invaded area (3%) has been treated to date, and that one of the two effective biological control agents has only recently been released (Impson et al. 2008), and is not yet present in the thicket biome. It appears therefore that not much progress has been made with the control of *Acacia mearnsii* in the thicket biome.

3.3.6 Indian Ocean Coastal biome

Chromolaena odorata is the most dominant invasive species in this biome, and it has received the bulk of funding for control costs (Table 3). Although a large proportion (80%) of the estimated invaded area has been treated over the past 15 years, there is no indication that the extent of the invasion has changed. A considerable effort has been made to find biological control agents for this significant invader species (31 agents have been considered, and 5 released, of which one causes “considerable” damage to the plant, Klein 2011). The overall degree of biological control achieved has yet to be determined, but is still localised and inconsequential (Table 4). *Chromolaena odorata* therefore remains a large and growing threat to ecosystem integrity in the biome.

3.3.7 Arid biomes

Alien plant control operations in all arid areas (the Nama karoo, succulent karoo, desert, and arid portions of savanna and grassland biomes in the Northern Cape Province) focussed on a single taxon (*Prosopis* species), which accounted for > 85% of the control costs in all arid biomes. Despite expenditure of 219 million rands, the control was only applied to a relatively small proportion (7%) of the estimated invaded area (Table 3). It also appears that *Prosopis* invasions are increasing at an exponential rate despite clearing efforts. The estimated extent of invasion grew by 363% between 1990 and 2007, from about 77 000 condensed ha in 1990, to 147 000 ha in 2002, 203 000 ha in 2003 and 360 000 ha in 2007 (van den Berg 2010). *Prosopis* trees have some useful properties, and for this reason biological control options have been limited to seed-feeding insects, which only achieve a negligible degree of control (Table 4). Economic studies have indicated, however, that the rapid expansion of *Prosopis* will result in the value of negative impacts exceeding the value of benefits in the near future, suggesting that a different approach to the control of *Prosopis* is needed (Wise et al. in press), and that the threat of ongoing invasion by *Prosopis* species remains a significant concern. Emerging invaders in arid biomes include the torch cactus, *Echinopsis spachiana*, which has spread from 39 quarter degree squares in 1996 to 75 quarter degree squares in 2011, almost doubling in area. The species has the potential to become a serious threat to ecosystem integrity in arid areas.

4. Discussion

4.1 The value of control

Invasive alien plants are often associated with serious negative economic consequences (Pimentel 2002, Perrings et al. 2010), and preventing or reversing these impacts is the primary goal of invasive alien plant control programs. In South Africa, the economic cost of alien plant invasions at current levels of invasion was estimated to be 6.5 billion rands annually (2008 values, De Lange and van Wilgen 2010); the prevention of such losses, especially those associated with loss of water resources was the primary reason for initiating Working for Water (van Wilgen et al. 2011a). Our assessment suggests, however, that the primary goal of preventing the erosion of ecosystem services is not being met at a national scale. The control operations have in many cases only reached a small percentage of the estimated invaded areas (for example, 7% of the estimated area under *Prosopis* invasions in arid areas, and 16% of *Acacia mearnsii* invasions in the savanna and grassland biome). Alternately, for many taxa where control operations have reached a significant portion of the invaded area, the impact has not been large. For example about half of the area under *Pinus* invasions in the fynbos has been subjected to control, with little apparent impact on the overall state of invasion. Similarly, *Chromolaena odorata* invasions have remained prominent, or grown, despite a significant proportion having been treated in the moist savanna and Indian Ocean coastal biomes. Although progress has been made with the suppression of several invasive taxa, it appears that most biomes remain under threat from several prominent species – notably *Pinus* in fynbos, *Acacia* in grassland, savanna and thicket, *Prosopis* in arid areas, *Campuloclinium macrocephalum* in grassland and *Chromolaena odorata* in the Indian Ocean coastal belt. The overall negative impacts of invasive alien plants may continue to grow therefore, unless more effective solutions can be found.

While the above summary points to a serious problem, it does not mean that control efforts to date have been entirely without benefit. Had the control not taken place, the situation would undoubtedly have been worse. Progress appears to have been made with the mechanical clearing of some species (Table 3), while others have been reduced in extent and impact by a combination of mechanical and biological control (Esler et al. 2008), or, in some cases, biological control alone (Klein 2011). One estimate suggested that, had no control been carried out, the annual economic losses from alien plant invasions would have been as high as 41.7 billion rands (instead of 6.7 billion rands), further, and that a significant proportion of these savings (between 5 and 75%, depending on the group of plants) arose from the biological control of invasive alien plants (De Lange and van Wilgen 2010). In addition, Working for Water was able to create 20 000 employment opportunities annually over 15 years in impoverished areas, that would not have been there had the program not existed.

In some areas, where control programs have focussed on smaller areas and adhered to systematic control schedules, significant progress has been made. For example, invasive alien plants have been eliminated from large sections of the formerly densely-invaded Table Mountain National Park (BWvW, personal observation). Nonetheless, our assessment suggests that the strategic approach of a comprehensive program that attempts to target many invasive alien plant species in many areas, using poverty-relief funding, needs to be reassessed if progress is to be made.

4.2 Options for increasing effectiveness

Working for Water's strategic plan (Anon. 2007) calls for, among other things, the prioritization of invasive alien plant species for management action, the development of indicators to underpin a monitoring program, and the implementation of such a program. A start has been made with the prioritization exercise (Nel et al. 2004; van Wilgen et al 2007; 2008b), but monitoring and evaluation has not been adequately resourced to date. The ongoing attempts to control a wide range of invasive alien plant species in the absence of adequate co-ordination and monitoring has been described as "a strategy of hope" (van Wilgen et al. 2011b). Key missing elements include (1) adequate integration of management interventions (mechanical clearing operations, biological control, and legislative compliance); (2) clear, time-based targets; and (3) protocols for adapting approaches as new information comes to light (van Wilgen et al. 2011b). Several options are available to increase effectiveness by making revisions to the strategic approach that has been adopted to date. These include:

(1) Investing an appropriate proportion of funds into the prioritization of control operations, planning, monitoring and evaluation. Working for Water has arguably initiated too many projects, and targeted too many species in too many areas, to be effective. One study (Roura-Pascual et al. 2009) concluded that "considerable progress in controlling the spread of invasive alien plants in fynbos ecosystems could be achieved by better coordination of management practices and by improving the quality of species distribution data". By setting clear goals, and targeting fewer species in selected priority areas, the available funds could almost certainly be used more effectively.

(2) Improved integration of mechanical and biological control. These two forms of control have seldom been deliberately co-ordinated, as they should be (Wood 2011). Where this has happened (see, for example Hoffmann et al. 1998), significant benefits have been reaped. The early release of biological control agents to allow establishment, and to affect a reduction in seed output and some suppression of plant growth or populations, before mechanical clearing proceeds can make a significant contribution to the success of the entire operation.

(3) Improving efficiency and professionalism. Working for Water's strategy of investing in the development of relatively inexperienced contractors, to create management capacity, and employing a largely untrained workforce, to alleviate poverty, has brought advantages and disadvantages. The advantages include the delivery of benefits to indigent people in rural areas where few other employment opportunities exist, and gaining political support, and thus substantial funding. The disadvantages include inefficiencies in control operations. Working for Water's records show that up to 9 follow-up visits are required for the control of *Acacia* species, and at least part of this is due to a lack of diligence in the application of standard control procedures. The expenditure of R155.5 million rands on the mechanical clearing of *Cereus jamacaru*, when biological control options were available to achieve complete control at a small fraction of the cost (Table 4), provides another example of a significant inefficiency that could arguably have been avoided had a more professional approach been adopted.

(4) Directing a greater proportion of the available funding to biological control research, where many successes have been registered (Table 4) and where many more are possible. Currently, spending on biological control is far lower than on other forms of control (about 3% of the total funds available) despite the significantly better returns on investment from biological control. In their review of the costs and benefits of biological control, van Wilgen and De Lange (2010) noted that "Mechanical and chemical forms of control, while effective in the short term, and often essential components of integrated control, are at best a holding action. Invasive alien plant species are never eradicated by mechanical and chemical clearing, and will re-invade cleared areas, requiring constant ongoing containment. The likelihood that funding for such operations can be maintained at the necessary levels in perpetuity is low. Biological control solutions therefore should be sought and implemented for as many weed species as possible, freeing up scarce resources for the control of invasive plant species for which no biological control options are available".

(5) Promoting a more widespread use of schemes of payment for ecosystem services. Some water utilities and municipalities have contracted Working for Water to control invasive alien plants in their water catchments, using payments for services (in this case water supply to users, Turpie et al. 2008). However, this practice in not widespread enough, and should be encouraged or even made mandatory, as the funding for control operations would both increase and be placed on a more sustainable basis.

(6) Dealing effectively with invasions on privately-owned land. Working for Water's has provided assistance to private landowners by clearing land, with the explicit understanding that landowners would then prevent re-invasion of cleared sites. By and large, landowners have not honoured such agreements, frequently citing Working for Water's inefficiencies (that effectively leave the land in an invaded state – see point 3 above) as a justification for not taking responsibility for ongoing maintenance. As most land in South Africa is in private ownership, a solution to this problem would be essential to the retention of gains made through initial clearing.

(7) Dealing with conflicts. Several important invasive alien plant species (notably trees in the genera *Pinus*, *Acacia* and *Prosopis*) are conflict species, as they bring both benefits and negative impacts. Studies have shown the economic benefits gains often exceeded by negative impacts, and that placing constraints on control options to protect benefits is not economically justifiable (De Wit et al. 2001; Hoffmann et al. 2011; Wise et al. in press). In such cases, political courage and sustained commitment will be required to ensure sustainable outcomes (through, for example, allowing expansion of biological control options to more damaging agents, van Wilgen et al. 2011b).

(8) Adopting a framework of adaptive management (Wilhere 2002; Stankey et al. 2005) to allow for ongoing improvement of management in a complex environment where the outcomes of management cannot be accurately predicted. Adaptive management will require changes to Working for Water's approach, including setting clear and achievable targets, introducing an

effective monitoring program to assess progress towards these targets, and accepting the flexibility to adapt approaches should targets not be met.

Gaining control of invasive species, and reducing their substantial impacts, is an extremely important component of natural resource management. Given the indications presented here that impacts have continued to grow in many areas despite significant investments in control suggests that changes to the strategy are needed if significant successes are to be achieved in controlling populations of invasive alien plants in South Africa.

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Table 1

Features of the terrestrial biomes in South Africa, and the major invasive alien species in each biome. Data are from Mucina and Rutherford (2006) and Henderson (2007)

Biome	Extent (km^2)	Proportion of biome remaining untransformed(%)	Features	Prominent invasive alien plant species
Fynbos	83 964	69	Mediterranean-climate, fire-prone, 1 – 2 m tall shrublands on nutrient-poor soils. High levels of diversity and endemism among plant species.	Trees and shrubs in the genera *Acacia* (wattles), *Pinus* (pines) and *Hakea* (shrubs in the family Proteaceae).
Grassland	354 953	65	Short-stature, relatively species-rich vegetation dominated by grasses, with few other life-forms present. Prone to frequent fire and subject to high levels of grazing.	Important trees include wattles (*Acacia* species), willows (*Salix* species), poplars (*Populus* species) and gums (*Eucalyptus* species), notably along rivers. Shrubs include *Rubus* species (brambles), *Pyracantha* species (firethorns) and cacti (*Opuntia* species).
Savanna	412 544	77	Characterised by the co-dominance of trees and grasses. The proportion of trees to grasses is determined largely by four interacting factors: soil fertility, rainfall, fire and grazing pressure. Our analysis divided savanna into arid and moist areas to accommodate comparisons to	Invasive species are dominated by the shrubs *Chromolaena odorata* (L.) R.M.King & H.Rob. (triffid weed) and *Lantana camara* L. (lantana). Important invasive trees include wattles (*Acacia* species), *Melia azederach* L. (syringa), *Solanum maurtitianum* Scop. (bugweed), *Psidium guajava* L. (guava) and *Jackaranda mimosifolia* D.Don. (jackaranda). Trees in the genus *Prosopis* (mesquite) are predominant in

			other surveys that used similar divisions.	arid parts.
Albany thicket	29 127	88	Dense, woody, semi-succulent and thorny vegetation, 2 – 3 m tall. Essentially fire-free due to low amounts of dead dry material and high proportion of succulents.	Invasive succulents, mainly cacti (*Opuntia* and related genera).
Nama karoo	248 728	98	Low, dwarf shrublands, with co-occurring grasses, succulents, geophytes and annuals. Small trees occur along drainage lines.	Trees in the genus *Prosopis* (mesquite). The shrub *Atriplex lindleyi* Moq. subsp. *inflata* (F.Müll.) P.G.Wilson (sponge-fruit salt-bush) and the cactus *Opuntia ficus-indica* (L.) Mill. (sweet prickly pear) are also predominant. The tree *Schinus molle* L. (pepper tree) is becoming increasingly widespread.
Succulent karoo	83 283	95	Highly diverse low dwarf shrublands with many succulents and low cover. The world's only arid biodiversity hotspot.	Trees in the genera *Acacia* (wattles), *Prosopis* (mesquite) and *Populus* (poplars), and the shrubs *Nicotiana glauca* Graham (wild tobacco) and *Atriplex lindleyi* Moq. subsp. *inflata* (F.Müll.) P.G.Wilson (sponge-fruit salt-bush) *and A. nummularia* Lindl. (old man saltbush). The cactus *Opuntia ficus-indica* (L.) Mill. (sweet prickly pear) is also predominant.
Indian Ocean coastal belt	14 282	51	Mixed vegetation characterised by juxtaposed fire-prone grasslands and fire-free forests.	The herbaceous shrubs *Chromolaena odorata* and *Lantana camara* are the most important invasive species. Additional species include *Caesalpinia decapetala*, *Cestrum laevigatum* and *Psidium guajava* L. (guava).
Forest	4731	94	Multilayered vegetation dominated by evergreen trees, ranging in height from 3m to 30 m. Occurs as scattered, fire-free patches of varying size.	Dominant invasive trees include wattles (*Acacia* species) and *Solanum mauritianum* Scop. (bugweed). *Chromolaena odorata* (L.) R.M.King & H.Rob. (triffid weed) and *Lantana camara* are important invasive shrubs.

Desert	7166	99	Dry areas (< 70mm mean annual rainfall) with sparse perennial vegetation of < 10% cover.	Invasions of *Prosopis* (mesquite) trees in dry river beds.

Table 2

Prominent invasive alien plant taxa in South Africa, and the cost of control by Working for Water between 1995 and 2008 for each taxon. Clearing costs are expressed as 2008-equivalent rands (1 US$ = approximately 7 South African rands).

Invasive alien plant taxon	**Growth form**	**Rank in terms of area occupied (Le Maitre et al. 2000).**	**Rank in terms of area occupied (Kotzé et al. 2010).**	**Rank in terms of prominence value (Henderson 2007).**	**Clearing cost (millions of rands)**
Acacia cyclops A.Cunn. ex G.Don (rooikrans)	Evergreen tree	1	7	4	63.2
A. dealbata Link (silver wattle)	Evergreen tree	12	1 (grouped with other wattle species)	10	86.9
A. mearnsii De Wild. (black wattle)	Evergreen tree	3	1 (grouped with other wattle species)	1	1055.4
A. melanoxylon R.Br. (blackwood)	Evergreen tree	26	25	25	31.8
A. saligna (Labill.) H.L.Wendl. (Port Jackson Willow)	Evergreen tree	4	8	2	56.5
Caesalpinia decapetala (Roth) Alston (Mauritius thorn)	Evergreen shrub	16	18	27	31.9
Cereus jamacaru DC. (queen of the night)	Spiny succulent tree	Not reported	17	51	155.5
Chromolaena odorata (L.) R.M.King & H.Rob. (triffid weed)	Scrambling shrub	14	4	11	207.5
Eucalyptus species (gum	Evergreen trees	11	2	13	214.1

trees)					
Hakea sericea Schrad. & J.C.Wendl. (silky hakea)	Evergreen shrub	10	11	41	95.2
Lantana camara L. (lantana)	Scrambling shrub	9	12	3	153.5
Melia azederach L. (syringe)	Deciduous tree	8	13	9	50.9
Cactaceae	Spiny, succulent trees and shrubs	7	5	5	40.9
Pinus species (pine trees)	Evergreen trees	6	3	14	290.5
Populus species (poplar trees)	Deciduous trees	24	6	7	26.7
Prosopis species (mesguite)	Evergreen trees	2	Not reported	12	323.3
Salix babylonica L. (weeping willow)	Evergreen tree	25	10	8	4.0
Solanum mauritianum Scop. (bugweed)	Evergreen shrub or small tree	5	9	6	69.4

Table 3

Estimates of area occupied at different times, area subjected to control, and cost of clearing for prominent invasive alien plant taxa (see Table 2) in major terrestrial biomes in South Africa. Clearing costs are expressed as 2008-equivalent rands. Estimates for area occupied in 1996, and 2007 are from Le Maitre et al. (2000) and Henderson (2007) respectively. Estimates for 2008 are from van den Berg (2010) for *Prosopis* and Kotzé et al. (2010) for all other taxa.

Biome	**Invasive alien plant taxon**	**Estimated area occupied**			**Control effort**	
		In 1996 (condensed ha x 1000)	**In 2007 (prominence value)**	**In 2008 (condensed ha x 1000, +/- CV%)**	**Area treated between 2002 and 2008 (condensed ha x 1000)**	**Cost of treatment between 1995 and 2008 (millions of rands)**
Fynbos	*Acacia cyclops*	285.6	27.2	48.4 (± 12.1)	6.1	62
	A. mearnsii	45.6	31.5	27.5 (+/-14.1)	32.1	488
	A. saligna	92.3	30.40	45.6 (+/- 12.1)	4.4	57.5
	Hakea species	39.6	3.84	36.6 (+/-13.6)	12.6	102
	Pinus species	50.4	11.22	58.5 (+/-14.0)	29.5	240
	Populus species	3.2	3.19	1.9 (+/- 12.1)	0.7	9.2
Grassland (excluding arid areas)	*Acacia dealbata* and *A. mearnsii*	110.1	42.2	310.8 (+/-14.0)	62.2	470
	Eucalyptus species	118.9	7.35	157.6 (+/-15.1)	5.5	65
	Populus species	5.8	14.19	43.4 (+/- 14.8)	0.9	11.9
	Salix babylonica	6.0	17.30	34.9 (+/- 14.8)	0.4	4.9
	Solanum mauritianum	41.3	10.6	7.1 (+/-13.6)	4.3	60
Moist savanna	*Acacia mearnsii*	28.4	10.2	103.7 (+/- 13.6)	4.5	56
	Cereus jamacaru	21.9	1.99	10.2 (+/- 16.2)	32.7	156
	Cactaceae species	47.0	11.76	18.7 (+/- 12.0)	33.3	179.6
	Chromolaena odorata	23.7	14.2	73.3 (+/- 14.1)	12.7	86

	Eucalyptus species	25.4	4.0	70.4 (+/- 14.9)	5.8	78
	Lantana camara	40.3	20.6	22.5 (+/- 14.2)	19.8	128
	Melia azedarach	58.8	12.00	10.0 (+/- 15.1)	3.8	29
	Solanum mauritianum	38.1	10.6	24.8 (+/- 15.5)	4.9	67
Forest	*Acacia melanoxylon*	1.0	14.2	0.1 (+/- 14)	0.3	7
	A. mearnsii	1.1	16.7	2.1 (+/- 11.4)	0.9	12
	Eucalyptus species	0.1	7.23	1.9 (+/- 13.6)	0.2	3
	Pinus species	0.2	7.86	4.2 (+/- 12.1)	0.5	5
Albany thicket	*Acacia mearnsii*	10.5	No data	17.7 (+/- 11.6)	0.4	61
Indian Ocean Coastal Belt	*Caesalpinia decapetala*	0.3	No data	0.4 (+/- 12.3)	0.2	7
	Chromolaena odorata	19.3	No data	19.0 (+/- 14.8)	15.4	96
	Lantana camara	8.0	No data	6.0 (+/- 12.0)	2.0	14
Nama Karoo (Northern Cape only)	*Prosopis* species	104.5	78.8	252.8	14.9	134
Succulent karoo (Northern Cape only)	*Prosopis* species	52.0	8.9	32.1	3.7	19
Arid savanna (Northern Cape only)	*Prosopis* species	51.3	No data	51.3	5.3	49
Desert	*Prosopis* species	3.9	No data	7.8	1.4	17

Table 4

Prominent alien plant taxa in South Africa (see Table 2), and the degree of biological control achieved for each taxon. The degree of control was assessed as follows: Complete: no other control measures are needed to reduce the weed to acceptable levels. Substantial: Other methods are needed to reduce the weed to acceptable levels, but less effort is required. Negligible: despite damage, control of the weed remains entirely reliant on the implementation of other control measures (after Klein 2011).

Invasive alien plant taxon	Biological control agents released	Degree of control achieved	Notes	Key references
Acacia cyclops	Seed feeder and flower galler	Substantial	Predicted that “there will be a substantial and sustained decline in abundance” of this species over time, as a result of depleted soil-stored seed banks.	Moran and Hoffmann (2011) Impson et al. (2011)
A. dealbata	Seed feeder	Not determined	Should agents reduce seed output substantially, mechanical clearing would still be needed to eliminate existing stands	Impson et al. (2011).
A. mearnsii	Seed feeder and flower galler	Not determined	Should agents reduce seed output substantially, mechanical clearing would still be needed to eliminate existing stands. Conflict of interest species, and biological control restricted to agents that do not damage the vegetative parts of the plant.	Impson et al. (2011) van Wilgen et al. (2011b)
A. melanoxylon	Seed feeder	Substantial	Control agents reduce seed output substantially, but mechanical clearing needed to eliminate existing stands. Conflict of interest species, and biological control restricted to agents that do not damage the vegetative parts of the plant.	Impson et al. (2011)
A. saligna	Seed feeder and fungal gall former	Substantial	Seed production and plant vigour both considerably reduced, resulting in significant declines in dominance.	Impson et al. (2011) Moran and Hoffmann (2011)
Caesalpinia decapetala	Seed feeder	Negligible	This species was not considered as a high priority for biological control research by Working for Water	Byrne et al. (2011)
Cereus jamacaru	Stem sucker and	Complete	Mechanical clearing has continued despite the	Paterson et al. (2011)

	stem borer		availability of highly effective biological control (Table 3).	
Chromolaena odorata	Leaf miner, stem borer and three species of leaf feeders	Not determined	One leaf feeder found to inflict considerable damage in very localised areas, but, overall, weed populations have not been suppressed	Zachariades et al. (2011a).
Eucalyptus species	None	Not applicable	Many *Eucalyptus* species are not aggressively invasive, and this group has not been considered for biological control.	None
Hakea sericea	Stem borer, seed feeder, stem gummosis disease, leaf and shoot borer, flowerbud feeder and green-seed feeder	Substantial	*Hakea sericea* appears to be declining as a result of the combined effects of mechanical clearing and biological control	Gordon and Fourie (2011) Esler et al. 2010.
Lantana camara	Thirteen agent species released and established. Damage to flowers, leaves and roots	Negligible to substantial control, depending on plant variety.	This species forms hybrids, which complicates the search for biological control options.	Urban et al. (2011)
Melia azederach	None	Not applicable	The exact area of origin of *Melia azedarach* is not known, so a source of potential biological control agents cannot be located.	None
Cactaceae	Cladode borers, cladode suckers, stem suckers and stem borers.	Complete (3 species) Substantial (8 species) Negligible (1 species) Not determined (2 species)	Fourteen species of Cactaceae (excluding *Cereus jamacaru*) have been subjected to biological control, including the genera *Austrocylindropuntia, Cylindropuntia, Harrisia, Opuntia and Pereskia*.	Paterson et al. (2011)
Pinus species	None	Not applicable	Conflict of interest species, and biological control	Hoffmann et al. 2011.

			research restricted to seed feeders	
Populus species	None	Not applicable		None
Prosopis species	Seed feeders	Negligible	Conflict of interest species, and biological control restricted to seed feeders (Wise et al. in press).	Zachariades et al. (2011b)
Salix babylonica	None	Not applicable		None
Solanum mauritianum	Flowerbud feeder and leaf sucker	Negligible		Olckers 2011