



Progress towards the control of invasive alien species in the Cape Floristic Region's protected areas

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Abstract This paper assesses progress towards the control of biological invasions in 18 protected areas (PAs) covering 677 584 ha in the Cape Floristic Region (CFR), and whether progress has been sufficient to achieve Target 6 of the Kunming-Montreal Global Biodiversity Framework. We used eight indicators for assessing the inputs (quality of the regulatory framework, money spent and planning coverage for species and protected areas), outputs (species and protected areas treated), and outcomes

(effectiveness of species and protected area treatments) of management. The estimated money spent over 13 years (2010–2022) was ZAR 976 million, or ZAR 75 million per year. Management plans for PAs were assessed as adequate over 78.5% of the area, but only six out of 226 regulated invasive species had species-specific control plans in place. A total of 567 alien species occurred in the CFR's PAs, 226 of which were regulated species (i.e. species that had to be controlled), 126 (55.8%) of which received some management. Spending was highly skewed, with over 60% of all funding spent on trees and shrubs in the genus *Acacia*. Management efforts reached 24% of

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the land within the CFR's protected areas, with higher coverage in national parks (60%) than in provincial nature reserves (9%). Management effectiveness was assessed as either permanent, effective or partially effective for 29 species (20 due to biological control), and ineffective for 25; for the remainder, there was either no management or effectiveness could not be evaluated. We conclude that some progress has been made with respect to controlling invasive alien species in the CFR, but that insufficient and declining funding remains a significant barrier to effective management. To increase efficiency, it will be necessary to secure additional funding from more diversified sources, make more use of biological control and prescribed fire, and regularly monitor the outcomes of management.

Keywords Biological control · Fynbos · Indicators · Kunming-Montreal targets · South Africa

Introduction

South Africa's Cape Floristic Region (CFR) covers 84 000 km², of which just over 10% falls within formally protected areas (hereafter PAs). The dominant vegetation of this region (fynbos) is a fire-prone shrubland with high levels of plant diversity and endemism (Rebello et al. 2006). The outstanding universal value of the CFR's PAs has been recognised through their proclamation as World Heritage Sites (van Wilgen et al. 2016a), and a large proportion of the country's Strategic Water Source Areas (Le Maitre et al. 2018) are within the CFR's PAs. All these PAs are invaded to varying degrees by alien plants, mostly trees and shrubs from Europe, North America and Australia. In addition, several invasive alien faunal species have established in the PAs, notably freshwater fishes. Active management to control these invasions has been ongoing since the 1970s (Fenn 1980), or earlier in some cases (Macdonald et al. 1989). This control has mainly focussed on invasive alien plants and has broadly taken two forms. The first involved physical removal of plants using hand-held or power tools in combination with the application of herbicides to prevent resprouting if needed (e.g. Fenn 1980), and the second involved biological control (Moran et al. 2013).

A recent review assessed the costs of alien plant control in PAs in the CFR between 1995 and 2014 (van Wilgen et al. 2016b). These costs amounted to ZAR 564 million (~38 million USD), most of which (90%) was expended on alien trees in the genera *Acacia*, *Pinus* and *Hakea* in that order. The study concluded that funding would need to be increased to reduce invasions to sustainably manageable proportions within the next 20 years. This conclusion was based on several assumptions, including that spread rates would not exceed 4% per year, that certain taxa would be removed from the control program to allow a focus on species of higher priority, and that best management practices would be adhered to. Under less favourable scenarios, the invasions would continue to grow.

Over the past 29 years, the South African government has provided funding for the authorities responsible for managing the CFR's PAs through its "Working for Water" programme (van Wilgen et al. 2022). In addition, substantial amounts have more recently been raised from the private sector to assist with control, largely in response to the potentially catastrophic impacts of growing invasions on the region's water resources (Stafford et al. 2018). In December 2022, the Conference of the Parties to the Convention on Biological Diversity adopted the Kunming-Montreal Global Biodiversity Framework. Target 6 of this framework calls for parties to "eradicate or control invasive alien species, especially in priority sites" by 2030. We consider the CFR's PAs to be priority sites for the reasons outlined above.

Eradication and control are separate goals, and it is important to be clear about this at the onset of any management interventions. Eradication refers to the complete removal of all individuals and propagules of a species from an area to which there is a negligible likelihood of re-invasion. Control refers to any action taken to prevent the regrowth and spread of an alien species (Richardson 2020), and it is usually highly unlikely that this will result in eradication. Management interventions need to be assessed in terms of their effectiveness, i.e. the degree to which they contribute to achieving management goals. For the goal of eradication, there would need to be measurable progress towards the total removal all individuals, although the criteria for declaring a successful eradication are not yet clear. The effectiveness of control should be

assessed in terms of its effect on population size and abundance of the target species (Table 1). Usually, the ultimate goal is taken to be reducing the populations to a maintenance level, i.e. a level at which the population can be sustainably contained at affordable levels in perpetuity. However, reducing alien species to maintenance levels might not result in the full restoration of native vegetation or could even worsen the situation through secondary invasions by other species or other unforeseen outcomes. Large programs that aim to deal with biological invasions by multiple species in a network of protected areas need to be periodically assessed in terms of their effectiveness for achieving eradication or control objectives. This paper assesses the inputs, outputs and outcomes of management aimed at achieving the goals of Target 6 in the PAs of the CFR over the past 13 years and makes recommendations for priority actions to improve management effectiveness.

Methods

Study area

Our study focussed on 18 PAs (>2000 ha) in the CFR, jointly covering 677 584 ha. The PAs included five national parks and 13 provincial nature reserve complexes in the CFR (Fig. 1; see online resource S1 for details). The nature reserves are managed by the provincial conservation authority (CapeNature), and the national parks by South African National Parks (SANParks). Alien plant control programmes that were initiated in the 1970s were substantially expanded in 1995 with the initiation of the Working for Water programme (van Wilgen et al. 1998). In addition to alien plants, there have been several projects that have sought to control alien faunal species in these PAs (Davies et al. 2020). The dominant vegetation (fynbos shrublands) is fire-prone and fire-dependent. Most of the area burns in unplanned wildfires (van Wilgen et al. 2010), and these wildfires promote the spread of the dominant alien trees and shrubs in the genera *Acacia*, *Hakea* and *Pinus*, complicating the planning and management of biological invasions (van Wilgen 2013).

Indicators and sources of information

We use a framework of indicators for assessing the inputs, outputs, and outcomes of invasive alien species control interventions (Wilson et al. 2018; Fig. 2; Table 1). The indicators cover three aspects of managing biological invasions—pathways of introduction and spread, the management of individual species, and the management of sites (in our case protected areas). Pathway interventions are usually implemented at a national scale, for example by regulating the import of species or seeking to detect unintentional or illegal imports at points of entry (Kumschick et al. 2020; Faulkner et al. 2016), and not at the scale of PAs. Trends in the management intervention indicators have been assessed at a national level in three successive national status reports (van Wilgen and Wilson 2018; Zengeya and Wilson 2020; 2023). This study focusses on evaluating progress towards Target 6 of the Kunming-Montreal Global Biodiversity Framework in the CFR's PAS. We pooled information from a range of sources to assign values to the indicators and to identify how effective the overall set of interventions has been for achieving the goals of Target 6.

South Africa's Alien and Invasive Species regulations promulgated under the National Environmental Management: Biodiversity Act (NEM:BA, Act 10 of 2004) provide a basis for assessing the indicator "quality of the regulatory framework". Laws are an important input into management, as they enable governments to regulate the cultivation and trade of alien species, and they can require citizens to take steps to control invasive species. The NEM:BA regulations were first published in 2014 and revised in 2020. The regulations apply at a national scale and are applicable at the scale of the CFR's PAs. The quality of the framework was assigned to a category (Table 1) by a semi-independent team, including someone from the legal profession, and the findings were included in the report by Zengeya and Wilson (2023).

"Money spent" is an important input indicator, as it enables all aspects of management – human resources, equipment, chemicals, transport, research, quality control and overheads. For the indicator "money spent", we used records of spending from the Working for Water programme's database for the years 2010 to 2022 (13 years). This database records all amounts paid to contractors operating in PAs each

Table 1 Metrics and categories for indicators of the inputs, outputs and outcomes of invasive species control programs in 18 protected areas in the Cape Floristic Region, adapted from Wilson et al. (2018)

Indicator	Metric	Categories
Input—Quality of the regulatory framework	Placement within a single category	None (regulations do not exist) Partial (regulations cover some aspects of management) Substantial (regulations cover most aspects of management) Complete (regulations cover all aspects of management)
Input—money spent	Expenditure per year, with annual values adjusted for inflation to present value in the year of reporting	Money spent in national parks Money spent in provincial nature reserves
Input—planning coverage for invasive species	The proportion of regulated invasive alien species present in the protected area that have a species-specific management plan in place	The proportion of regulated species where the adequacy of the plan is assessed for each species as: Absent (no plan exists) Inadequate (plans cover only some essential aspects adequately) Partially adequate (plans cover most essential aspects adequately) Adequate (plans cover all essential aspects adequately)
Input—planning coverage for protected areas	The proportion of land within protected areas that is covered by current management plans	The proportion of the total extent of all protected areas where the adequacy of the plan is assessed as: Absent (no plan exists) Inadequate (plans cover only some essential aspects adequately) Partially adequate (plans cover most essential aspects adequately) Adequate (plans cover all essential aspects adequately)
Output—species treated	The proportion of regulated invasive alien species present in protected areas that have been the subject of a management intervention	No further breakdown
Output—protected areas treated	The proportion of protected areas that needs to be managed that is being managed	No further breakdown

Table 1 (continued)

Indicator	Metric	Categories
Outcome—effectiveness of species treatments	The proportion of species assigned to categories of management effectiveness	<p>The proportion of regulated species where the treatment outcome is assessed as:</p> <p>None—there has been no treatment</p> <p>Not evaluated -there has been some treatment, but effectiveness has not been evaluated</p> <p>Ineffective—There is no discernible change in the rate at which the species is increasing</p> <p>Partially effective—the rate of increase in extent or abundance has slowed</p> <p>Effective—the extent or abundance is decreasing or has ended up below a management threshold, but management is continuing</p> <p>Permanent—there is no more active management and despite this the population remains below the management threshold</p>
Outcome—effectiveness of protected area treatments	The proportion of protected areas assigned to categories of management effectiveness	<p>The extent of protected areas where the treatment outcome is assessed as:</p> <p>None—there has been no treatment</p> <p>Not evaluated—there has been some treatment, but effectiveness has not been evaluated</p> <p>Ineffective—There is no discernible change in the rate at which the invaded area or abundance of species is increasing</p> <p>Partially effective—the rate of increase in invaded area has slowed, or the or abundance of species has been reduced</p> <p>Effective—the invaded area, or population size of invasive species is decreasing or has ended up below a management threshold, but management is continuing</p> <p>Permanent—there is no more active management and despite this the populations remain below the management threshold</p>

year, and this money is the primary (and often the only) source of funding for managing invasive species. The money covers wages, allowances, clothing, equipment, transport, training and administration fees for the contractor. The Working for Water programme, which administers these funds, incurs overheads amounting to 22.6% (van Wilgen et al. 2022). Both SANParks and CapeNature also add overheads amounting to 18% to cover the management costs (salaries and running costs for staff who manage the contractors) and a further 7.58% to cover support activities (GIS data capture, monitoring of compliance and quality of work). We added these overheads to the amounts paid to contractors, and then adjusted

the annual amounts to 2022 values for South African rands (ZAR; 1 USD = ~18 ZAR) to account for inflation, by using annual inflation rates (O'Neill 2021). In addition, we included spending by the Greater Cape Town Water Fund (Stafford et al. 2018) which has since 2020 secured substantial additional funding for the control of invasive alien trees in the water catchment areas for the city. These areas are also within the PAs included in this study. Progress on spending is tracked and is available on the Fund's website (<https://public.tableau.com/app/profile/waterfunds/viz/GCTWFDSSv1/PublicDSS>).

The development of “Invasive species management programmes” is a requirement under South

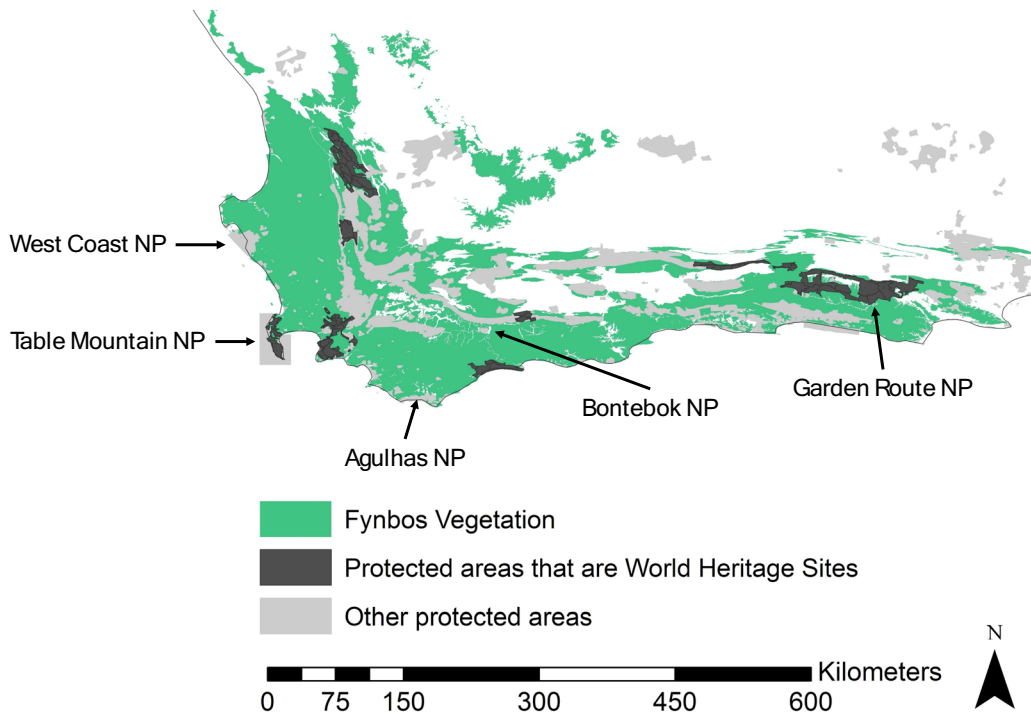
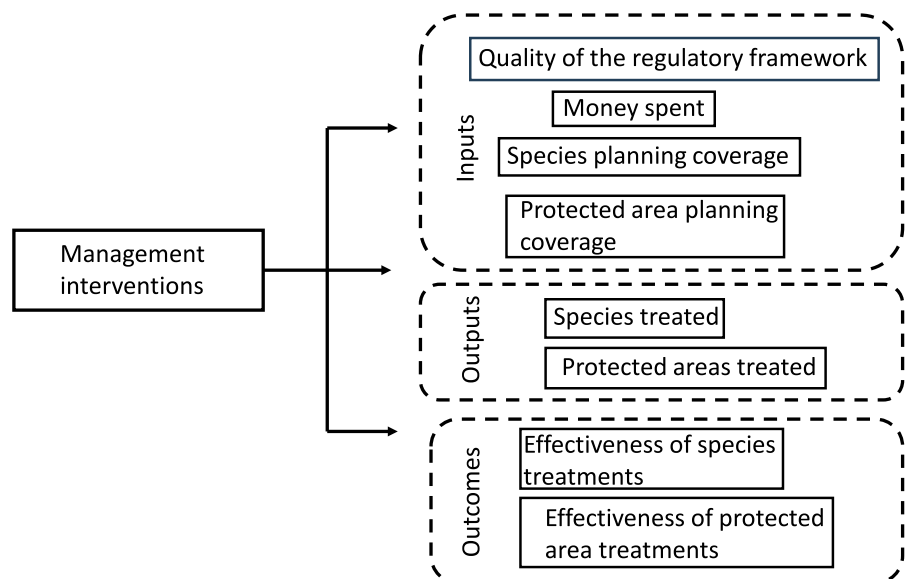


Fig. 1 The location of protected areas in the Western and Eastern Cape Provinces, South Africa. Protected areas that are also World Heritage Sites are shaded in black, and other protected areas are shaded grey. The location of five national parks is indicated; other protected areas are provincial nature

reserves. Green shading shows the original extent of fynbos vegetation, which covers 83 946 km²; 68.4% remains untransformed and 10.1% lies within protected areas (van Wilgen 2013)

Fig. 2 Indicators associated with management interventions for controlling biological invasions in terms of inputs, outputs and outcomes (after Wilson et al. 2018)



African law [NEM:BA Sect. 75 (5)]. These programmes would provide a basis for assessing the indicator “species planning coverage” but to date no such programmes have been formally approved (Zengeya and Wilson 2023). Should such plans be developed, they would apply at a national scale and would be relevant if the species concerned was present in the CFR's PAs. Management plans do however exist for species that are potential targets for national eradication (Wilson et al. 2013), and we assessed those where the target species occurred in the CFR's PAs, using the criteria in Table 1.

For the input indicator “protected area planning coverage”, we examined management plans for invasive alien species for all PAs. PA management plans were assigned to categories of adequacy depending on how many of six essential criteria were included in the plan (the criteria were a list of all invasive species present; a description of the land on which they occur; a description of the extent of invasion; an account of historic control efforts; a description of control methods to be used; and the presence of measurable indicators of progress). A criterion was only regarded as having been met if the description contained sufficient detail to provide a basis for informing management of at least the dominant invasive alien species across the entire PA. Plans were rated as *adequate* if all six criteria were adequately addressed, as *partially adequate* if four or five criteria were adequately addressed, or as *inadequate* if three or less of the criteria were adequately addressed (Zengeya and Wilson 2023). Protected area size was considered when assigning a percentage to each category of adequacy, i.e. the proportions within categories of adequacy were weighted by area.

For the output indicator “species treated”, we compiled a list of all alien species that had been recorded in PAs. The list was based on (1) systematic surveys of alien species in PAs (e.g. Baard and Kraaij 2014; Foxcroft et al. 2017) which are maintained and updated as new information becomes available; (2) species listed as dominant invasive alien plants or vertebrates in PA management plans; (3) records of spending from the Working for Water programme's database for the years 2010 to 2022; (4) species known to occur in the CFR's PAs that are being managed through a separate program as potential national eradication targets (Wilson et al. 2013); and (5) additional species present

in the CFR's PAs that were targeted through ongoing biological control (Zachariades 2021). Selected invasive alien species are regulated under NEM:BA regulations, and we noted the regulatory category for each species (see Online Resource S2 for details). In addition, we noted for each species whether there had been any management intervention intended to control it between 2010 and 2022, either through mechanical or chemical clearing, biological control, or as a potential target for national eradication. The cost of control for each species is recorded in the Working for Water records, and we used this information to determine the amount of effort that went into the management of individual species.

For the output indicator “protected areas treated”, we used spatial records of land parcels within PAs subjected to control using funding from the Working for Water programme. Each PA is divided into several land parcels which are then scheduled for management as funds become available, and these interventions are captured by Working for Water on a spatial database. Ultimately, the entire PA should receive management as there are no areas that are entirely free of alien plants. However, some land parcels did not receive treatment between 2010 and 2022 because they were not easily accessible or not heavily invaded, and because funds were insufficient to reach all land parcels. Some land parcels received repeated treatments (usually an initial clearing and one or more follow-up treatments to remove seedlings or regrowth), but each land parcel was counted only once, regardless of the number of treatments received.

The outcome indicator “effectiveness of species treatments” was estimated by assigning each species to a category of treatment effectiveness as described in Table 1. The effectiveness for individual species was based on assessments of biological control (Zachariades 2021) or on other published research studies (see Online Resource S2 for details). In cases where no information on control effectiveness was available, the species was placed in the category “not evaluated” (Table 1).

Very few reliable data were available to inform the outcome indicator “effectiveness of PA treatments” as there is no effective monitoring of progress in this regard (van Wilgen et al. 2020; Zengeya and Wilson 2023). Some research studies have

examined individual PAs, and these are reported where available.

Results

Management inputs

Quality of the regulatory framework

The quality of South Africa’s regulatory framework was assessed as partial at a national scale in successive status reports (Zengeya and Wilson 2020; 2023). Although the framework is far-reaching, and there is ongoing work to strengthen it (Wilson and Kumschick 2024), a few shortcomings remain. These include the absence of a policy or strategy to guide the implementation of the regulations at a national scale, which is seen as a weakness (Lukey and Hall 2020). At the scale of the CFR’s PAs, the regulations impose a responsibility on the landowners (in this case SANParks and CapeNature) to take steps to control listed invasive alien species. Agencies appointed to manage PAs are in any case mandated to control biological invasions, but the existence of this framework provides legitimacy for the removal of invasive species in cases where public resistance to such control occurs (van Wilgen 2012).

Money spent

Spending by the Working for Water programme on the management of invasive alien plants in the CFR between 2010 and 2022 amounted to ZAR 905 million (2022 values of ZAR; Fig. 3). Individual PAs received between ZAR 1.3 and 367 million, with over 90% being spent in the five national parks (Agulhas, Bontebok, Garden Route, Table Mountain and West Coast). Spending has fluctuated in real terms over the period examined here (Fig. 4). Notably though, spending on national parks has been sustained (and recently increased), while spending on the provincial nature reserves has declined, with no funding being made available in 2018 and again in 2023 and 2024 (the latter years not shown in Fig. 4).

Money from additional sources has also been spent on the control of biological invasions in the CFR’s PAs. The Greater Cape Town Water Fund (Stafford et al. 2018) has raised ZAR 313 million to date, of which ZAR 125, 118 and 69 million was obtained from the City of Cape Town, philanthropists and foundations, and business corporations respectively (a small proportion was also provided by Working for Water, accounted for above). Spending on control operations began 2020, when ZAR 9.9 million was spent (a further ZAR 91.6 million was spent between 2021 and 2023, and the budgeted amount for 2024 is ZAR 103.8 million). A survey of 52 volunteer groups from the Western Cape who clear invasive plants by Jubase et al. (2021) estimated that their work could be

Fig. 3 The amount of money spent between 2010 and 2022 in 18 protected areas in the Cape Floristic Region

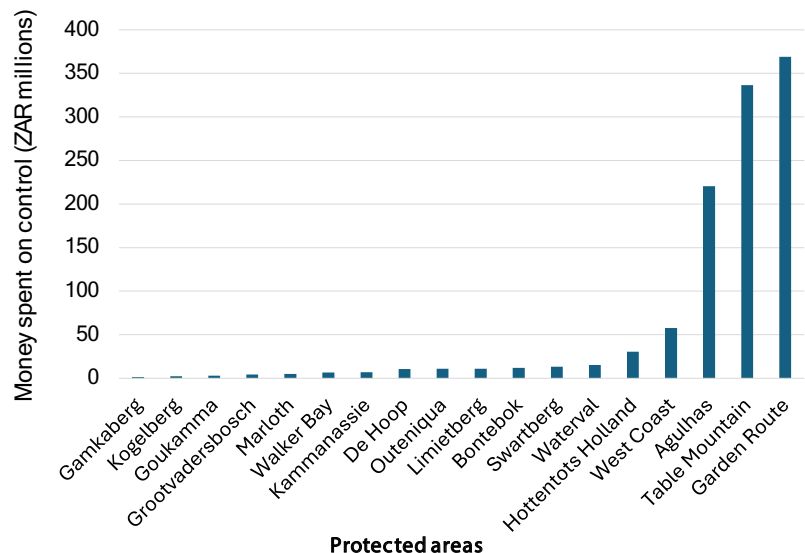
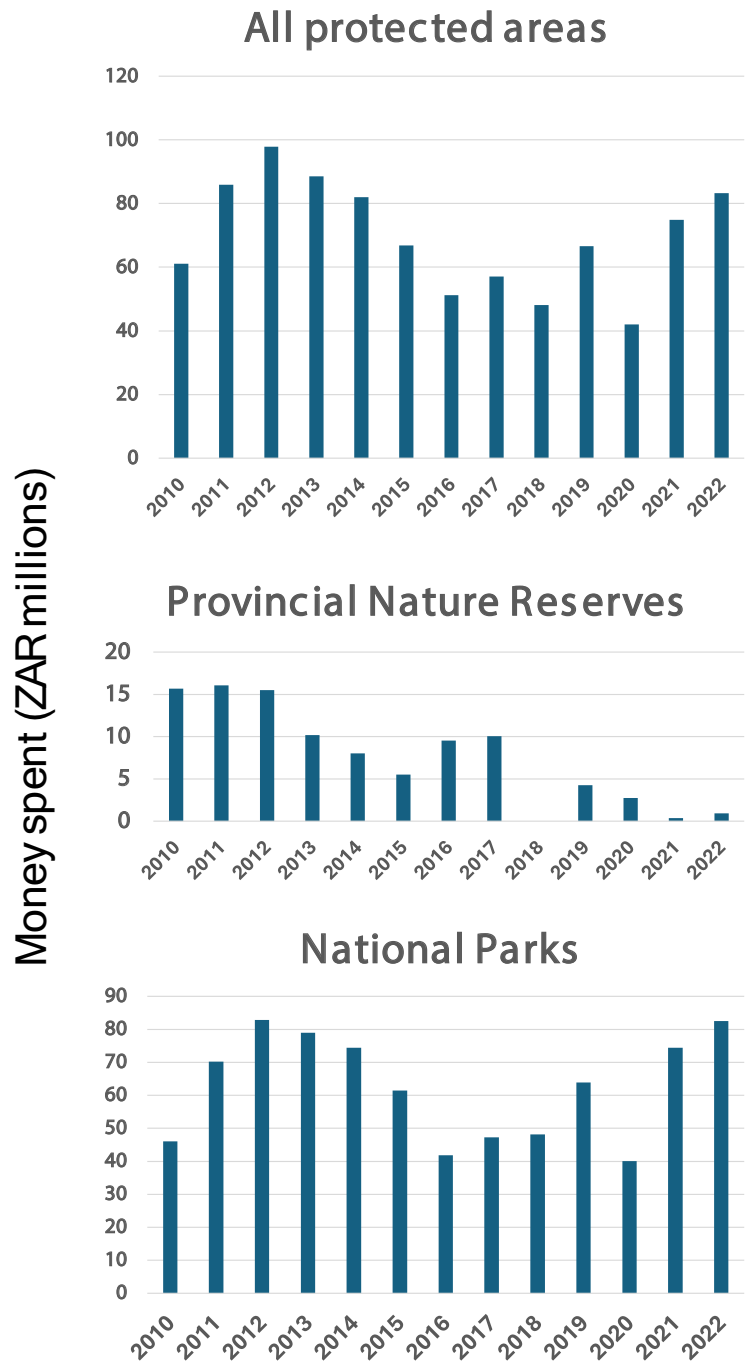


Fig. 4 The amount of money spent by the Working for Water programme per year between 2010 and 2022 on invasive alien plant control in all protected areas > 2000 ha in the Cape Floristic Region, showing a comparison of spending in provincial nature reserves and national parks. Note that the scales for money spent differ



valued at ZAR 5 106 241 annually. Much of this work took place inside of PAs, but this has not been accurately quantified and is not included here. An estimate of the money spent on managing invasions in the PAs of the CFR between 2010 and 2020 by Working for Water and the Greater Cape Town Water Fund would

therefore be around ZAR 976 million, or ZAR 75 million per year.

Planning coverage for species

Nine management plans were developed for species targeted for, or potentially targeted for, nationwide eradication in the CFR by the South African National Biodiversity Institute, which reports regularly on progress towards the goal of national eradication (Zengeya and Wilson 2023). Six were for regulated species and three for unregulated species. All plans were assessed as adequate except one (for *Acacia stricta*, a regulated species) which was scored as partially adequate. The indicator for species planning coverage was therefore 2.6% (i.e. plans are in place for six out of 227 regulated species).

Planning coverage for protected areas

Management plans have been drawn up for all 18 PAs considered here, so planning coverage was 100%. Most (78.5%) of the area was assessed as being covered by adequate plans, while plans were partially adequate or inadequate for 18.5% and 3% of the area respectively (Fig. 5). In terms of national legislation (the National Environmental Management: Protected Areas Act, Act 57 of 2003), all PAs must develop and implement management plans. These high-level plans did not deal in sufficient detail with the management

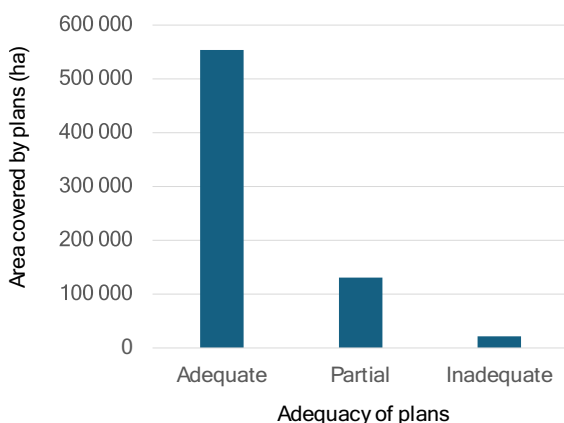


Fig. 5 The area covered by current management plans for the control of invasive species in 18 protected areas in the Cape Floristic Region, with assessments of the adequacy of plans (see text for assessment criteria)

of biological invasions, and separate plans that focus on invasions were needed. In 2017, very few plans dedicated to the management of biological invasions existed, and those that did were predominantly assessed as being inadequate (van Wilgen and Wilson 2018). It has subsequently become a requirement to develop management plans to obtain funding from the Working for Water programme. There has thus been a marked improvement in the number of plans for PAs in the CFR, as well as in their adequacy (Zengeya and Wilson 2023).

Management outputs

Species treated

A total of 567 alien species have been recorded in the CFR's PAs, of which 226 were regulated species. The number of alien species per PA ranged from 11 to 294 (all species), or 7 to 126 (regulated species), but this wide range reflects that some PAs had been more thoroughly surveyed than others. PA management plans listed 33 plant and 14 vertebrate invasive alien species as dominant and/or particularly problematic (see Online Resource S1 for details).

Of the 226 regulated species, 126 received some management, so the indicator (proportion of regulated species that are managed) is 55.8%. A further 45 unregulated species were also managed. Of the managed regulated species, most (121) were plants, and only five were faunal species. These included one amphibian (the guttural toad *Amietophrynus gutturalis*), two freshwater fish species (the common carp *Cyprinus carpio* and the smallmouth bass *Microp-terus dolomieu*) and two mammals (the feral pig *Sus scrofa* and the Himalayan thar *Hemitragus jemlahicus*). The dominant vertebrates listed in management plans were mostly freshwater fish (nine species), but comparatively little effort has gone into their management (Online Resource 2).

The bulk of spending on the control of individual invasive alien plant species in five national parks was focused on a relatively small number of the most widespread and dominant invasive species in the CFR's PAs. Each national park managed on average 78 species per park (range 23 to 147 species per park), but in each case >95% of the money was spent on only 15 species. The five species that received most funding were *Acacia saligna*, *A.*

cyclops, *A. mearnsii*, *A. melanoxylon* and *Pinus pinaster*, in that order. For the genera *Eucalyptus*, *Hakea* and *Pinus* many records of control efforts were only reported at the genus level so an accurate picture of spending by species is not available. However, more than two thirds (68%) of the spending was on Australian trees and shrubs in the genera *Acacia* and *Paraserianthes*, followed by pines (genus *Pinus*, 12% of spending), gums (genus *Eucalyptus*, 9% of spending), hakeas (genus *Hakea* 4% of spending) and Australian myrtle (*Leptospermum laevigatum*, 1% of spending) (Fig. 6).

The same pattern of skewed spending was also found in provincial nature reserves. Although 76 species received some treatment, >95% of the money was spent on only 15 species. The five species that received most funding were *Acacia mearnsii*, *Pinus pinaster*, *A. saligna*, *A. longifolia* and *Hakea sericea*, in that order. Over half of the spending (52%) was on the genera *Acacia* and *Paraserianthes*, followed by *Pinus pinaster* (19%), *Hakea sericea* (15%), gums (genus *Eucalyptus*, 6%), and two shrub species (*Rubus cuneifolius* and *Sesbania punicea*, 2% of spending, Fig. 6).

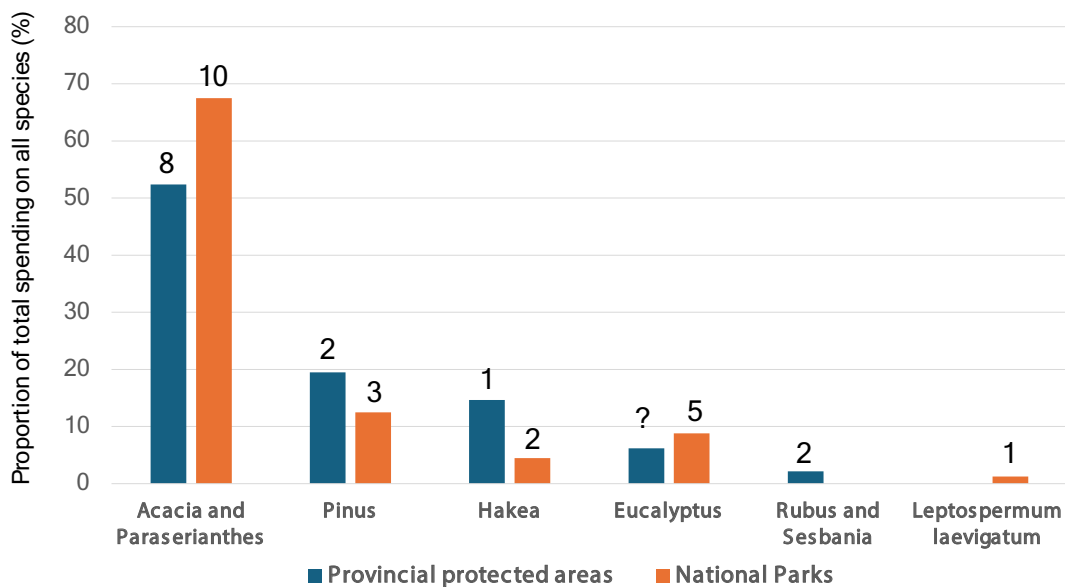


Fig. 6 The proportion of all spending on invasive alien plant control in five national parks and in 13 provincial nature reserves in the Cape Floristic Region between 2010 and 2022.

The taxa shown accounted for >95% of all spending. Numbers above the bars show the number of species recorded as treated in each taxon

Table 2 The proportion of land within protected areas in the Cape Floristic Region that received management arising from financial support from the Working for Water Programme between 2010 and 2022

Protected area	Extent of protected area (ha)	Proportion of area that received management (%)
Agulhas National Park	21 693	97
Bontebok National Park	2432	100
Garden Route National Park	115 782	34
Table Mountain National Park	26 554	90
West Coast National Park	34 177	93
All national parks	200 638	60
All provincial nature reserves	476 946	9
All protected areas in the Cape Floristic Region	677 584	24

Protected areas treated

Around one quarter of the land area within the CFR's PAs received management in the form of initial clearing and follow-up operations funded by the Working for Water programme between 2010 and 2022, i.e. the indicator for PAs treated was 24% (Table 2). This varied between individual PAs, with 60% of the land within national parks receiving some management on average, compared to 9% for provincial nature reserves. Management was carried out on >90% of land in all national parks except the Garden Route, where only 34% of the area received treatment. The Garden Route is the largest national park in the CFR, with substantial areas that are not accessible by control teams. The relatively low quantum of funding allocated to provincial nature reserves (Fig. 3) resulted in a much smaller proportion (9%) of land receiving treatment between 2010 and 2022 in those PAs. In addition, due to declining funding in recent years (Fig. 4), the area treated fell from a mean of 14% between 2010 and 2017 to 1% between 2018 and 2022. The above figures do not reflect work carried out due to funding from the Greater Cape Town

Water Fund. In the Hottentots-Holland and Limietberg Nature Reserves, the Fund estimated that invasions would need to be cleared from 61 789 ha. To date (end of 2023) 30 972 ha (50.1% of the invaded area) has been cleared by the Fund. The program is therefore on track to meet its target of completing the initial clearing within five years of initiating operations in these two PAs.

Management outcomes

Effectiveness of species treatments

Eight of the 226 regulated alien plant species in the CFR's PAs were assessed as being under permanent control due to biological control, and no further management should be necessary (Table 3). These include three cacti, two aquatic plant species, and the shrubs *Hypericum perforatum*, *Paraserianthes lophantha* and *Sesbania punicea* (see Online Resource S2 for details). A further 14 species are under effective control in that populations have decreased where control is implemented, but the control efforts continue. Biological control accounts for five of these species

Table 3 Effectiveness of management interventions for 227 regulated invasive alien species in 18 protected areas in the Cape Floristic Region. See Table 1 for definitions of categories

Category of management effectiveness	Number of species	Notes	Sources
Permanent	8	All are plants under biological control, and no further management is necessary	Wood and Den Breeÿen (2021) Zachariades (2021)
Effective	14	Five plant species are under biological control; six plant species are targets for national eradication and populations are closely monitored; populations of two mammal and one freshwater fish species have been reduced	Castañeda et al. (2020) Esler et al. (2010) Impson et al. (2024) Jacobs et al. (2014) Kaplan et al. (2014) King et al. (2021) Le Roux et al. (2010) Riddin et al. (2016) Weyl et al. (2014) Zachariades (2021) Zenni et al. (2009)
Partially effective	7	All are plants where mechanical and/or chemical control methods are more effective due to biological control	Zachariades (2021)
Ineffective	11	Indications are that species continue to spread despite control	Davies et al. (2020) Henderson and Wilson (2017) Zachariades (2021)
Not evaluated	86	There are no monitoring data against which to assess effectiveness	
Not managed	100	Species are present but there is no record of any management	

(three cacti and two trees in the genus *Acacia*), and treatments were assessed as effective for six plant species that are targets for national eradication, and thus were being carefully monitored. The remaining three species where management was assessed as effective were vertebrates. The first involved an attempt to eradicate Himalayan thars (*Hemitragus jemlahicus*) from Table Mountain National Park. The population was reduced from hundreds of individuals to very low numbers, but complete eradication was not achieved (Davies et al. 2020). The other was attempts to extirpate feral pigs (*Sus scrofa*) from four PAs. Hundreds of animals have been removed, and managers are optimistic that local extirpation will be achieved. The remaining species was a freshwater fish species (*Micropterus dolemieu*) that had been successfully extirpated from a stretch of river. Control was assessed as partially effective for seven species. All are plants where biological control has reduced the invasive potential of the target species to a point where mechanical and/or chemical control has become more effective (see, for example, Moran and Hoffmann 2012). Control was assessed as ineffective for 11 plant species as populations continued to spread despite management interventions (see, for example, Henderson and Wilson 2017). For the remaining regulated species, there was either no management (100 species), or the effectiveness of management could not be assessed (86 species).

Effectiveness of protected area treatments

The ongoing absence of formal systems that monitor the outcomes of PA treatments remains an obstacle to the assessment of their effectiveness across all PAs (Zengeya and Wilson 2023). A relatively small number of research studies have more accurately estimated effectiveness of PA management interventions, and the findings vary. On the one hand, good progress has been made towards clearing invasive alien trees and shrubs in some PAs, for example in the Table Mountain National Park (Cheney et al. 2020), and the catchment of the Berg River (within the Hottentots-Holland and Limietberg Nature Reserves; Fill et al. 2017). One study estimated that the cover of invasive pine trees in the Limietberg Nature Reserve would have been 50% higher had it not been for control operations funded the Working for Water programme (McConnachie et al. 2016). Fine-scale data

are available for alien species in the Table Mountain National Park (Cheney et al. 2020). Here, control operations cleared 22 875 ha between 2002 and 2020, and each treatment was followed up an average of 4.2 times (some areas required more follow-up treatments than others). In addition, the average return interval between repeat treatments was reduced in key areas of the park to allow for follow-up on a <2-year cycle to ensure that *Acacia* species were prevented from maturing and replenishing soil-stored seed banks. Overall, invasions across 18 097 ha (79% of the invaded area within the Table Mountain National Park) have been reduced to a maintenance phase (i.e. reduced to a low enough level that they can affordably be contained at that level in perpetuity).

On the other hand, some studies have found that control interventions have not followed best practice, leading to inefficiencies (McConnachie et al. 2012; Kraaij et al. 2017). Overall, van Wilgen et al. (2016b) concluded that reducing invasions in the CFR's PAs would require additional funding and stricter adherence to best management practices.

Discussion

Management inputs

Regulation

The quality of South Africa's regulatory framework for managing biological invasions was assessed as partial at a national scale. The regulations require forestry companies to obtain a permit to operate plantations if the species that they cultivate are listed as invasive. In the CFR, many alien forestry species (notably trees in the genus *Pinus*) are listed as invasive as they spread from forestry plantations into adjacent PAs. One of the requirements for a permit to cultivate and trade in listed invasive species is that the applicant must have demonstrated that adequate measures will be taken to prevent the spread of the relevant invasive species. However, the responsible minister has exempted plantations established before 2014 (when the regulations came into effect) from the requirement to obtain a permit, due to the impact that enforcing such conditions would have had on an important contributor to local economies. Thus, a substantial area of commercial forestry remains as

an unregulated seed source for re-invading adjacent areas that have been cleared. Although recent amendments to the regulations were considered to have improved the regulatory framework (Zengeya and Wilson 2023), the minister's exemption has simultaneously weakened the quality of the framework in the case of PAS in the CFR.

Money spent

Spending on the control of biological invasions in the PAs of the CFR has amounted to around ZAR75 million annually. Spending by the government's Working for Water programme has however declined in more recent years (2023 and 2024, not reported here), and the distribution of funds has become highly skewed. The bulk of funding currently goes to national parks, and the amount made available to provincial nature reserves has declined markedly (Fig. 4). This has been offset to some degree by funding from the Greater Cape Town Water Fund, but these funds are earmarked for use in two PAs within the water catchments of Cape Town only, leaving many provincial nature reserves without funding. Even if the funding was more equitably distributed, it would likely be insufficient to contain spread everywhere. Two studies have compared actual costs to those estimated at the start of control interventions and found that (1) actual costs were three to seven times greater than originally estimated; and (2) although good progress had been made, the goals of reducing invasions to acceptably low maintenance levels had not yet been met in some areas (Fill et al. 2017; van Rensburg et al. 2017). In addition, van Wilgen et al. (2016b) estimated that funding levels would need to be at least double the historic levels if invasions were to be brought down to maintenance levels within a decade.

Funds are disbursed by Working for Water to both SANParks and CapeNature. CapeNature is required to tender annually for these funds, requiring byzantine processes that hold up operations. This requirement does not apply to SANParks, which is an entity within the same department as Working for Water, and funds can simply be transferred to them without requiring tenders to be prepared and evaluated, and contracts issued and approved. This would explain at least some of the unequal distribution of funds between these two entities.

It remains unlikely that sufficient funding will be secured to deal with the full extent of invasions everywhere. Dealing with this reality would require prioritization and triage, in line with Target 6 guidelines (see also van Wilgen et al. 2016b). For example, the provision of adequate funding has resulted in the achievement of a maintenance phase in the Bontebok, Table Mountain and West Coast National Parks, illustrating the value of providing adequate funding to selected areas. However, making decisions about which areas to fund and which not to fund will not be easy. Nonetheless, a case could be made that the PAs of the CFR should receive priority given that they are recognised as World Heritage Sites, and that most are also located within Strategic Water Source Areas.

The importance of biological control

Biological control has made a disproportionate contribution to bringing invasive alien plant species under effective control. Control was assessed as either permanent, effective or partially effective for 20 species due to biological control, thus making up 70% of the 29 species in these categories (Table 3). These included trees and shrubs in the genera *Acacia*, *Hakea*, *Hypericum*, *Paraserianthes* and *Sesbania*, cacti (*Opuntia* species) and aquatic plants (in the genera *Azolla*, *Pontederia* and *Salvinia*). Data are not available to break the cost of developing the biological control agents down to the target species. However, several studies have indicated that biological control has brought some important and dominant invasive plants under effective control in the CFR (e.g. Esler et al. 2010; Impson et al. 2024; Moran and Hoffmann 2012; Zachariades 2021). A recent assessment of alien plant spread across South Africa (Henderson and Wilson 2017) found that the increase in invasive plants has only slowed down, or the invaded area has contracted, over 23 years when biological control was part of the management approach. The returns on investment from this biological control are substantial (De Lange and van Wilgen 2010; van Wilgen et al. 2020), with estimated benefit:cost ratios ranging from 8:1 (for *Sesbania punicea*) to 665:1 (for *Acacia longifolia*, van Wilgen and De Lange 2011). Until recently, the Working for Water invested 12.6% of its annual budgets supporting biological control and implementation (van Wilgen et al. 2022), but this

funding has recently been discontinued as part of the funding cuts cited above.

The need for alien species management plans

Species management plans had only been prepared for 2.6% of the 226 regulated alien species in the CFR's PAs, all of them targets for national eradication. Plans for the control of invasive alien species are necessary to provide guidance on the appropriate use and integration of available techniques, and for the strategic management of species at a landscape scale. Species management plans must provide well-defined guidelines on the most effective combination and deployment of methods that will maximise efficiency, and they must be clear on how to deal with species where conflicts of interest exist. Such plans are required for all regulated species, not just those that are targets for eradication, and are catered for in law.

Management plans need to provide details of techniques best suited to the ecology of the species concerned. Given the extensive invasions of some plant species, often in rugged and inaccessible terrain, manual clearing should be carried out using the most effective equipment. This was recognised at an early stage, when Fenn (1980) described the essential role played by power tools such as chain saws and brush cutters in clearing dense stands of *Hakea sericea*. The Working for Water programme has a policy of maximising employment using manual labour without power tools as far as possible, which increases the number of people employed but decreases effectiveness. Effectiveness can also be increased by prioritising scattered infestations for early control (van Wilgen et al. 2001). Guidelines on how to combine such approaches with other techniques such as the use of fire, herbicides and biological control can assist in increasing control efficiency. Modelling exercises suggest that, unless control efforts can be more effectively implemented, and focussed on priority areas, then the reduction of invasions to below an acceptable threshold (e.g. reducing *Acacia* density to below one plant per ha) may not be achieved (Cheney et al 2020; van Wilgen et al. 2016b).

Conflict species are particularly problematic, and species management plans are needed to provide guidance on how and where they should be managed. Research has estimated large impacts of invasive alien plants in the CFR because of reductions in water

resources, biodiversity, and pastures (van Wilgen et al. 2008), and damage due to increased fire intensity (Kraaij et al. 2018). The cost of these impacts in the CFR was estimated in 2010 to be ZAR2.5 billion annually (De Lange and van Wilgen 2010). Despite this evidence of costly impacts, alien trees are often regarded as desirable as they are seen as attractive and shady, providing habitat for birds and mammals, preventing excessive erosion, and assisting in mitigating against climate change (van Wilgen 2012). Alien fish are highly valued by freshwater anglers as they provide recreational angling opportunities as well as being a source of food. The government failed to list trout (*Oncorhynchus mykiss* and *Salmo trutta*) as invasive alien species in its 2020 revisions of the regulations due to considerable public resistance (Wilson and Kumschick 2024), and therefore cannot require their control or prohibit their introduction to new areas. The invasive alien tree fern *Sphaeropteris cooperi* was similarly removed from a list of proposed regulated alien species due to its popularity in the nursery trade. Culling programs against alien birds and mammals are also often strongly opposed. These issues can lead to strong resistance often involving influential individuals, and species management plans are needed to identify widely acceptable solutions for managing these species (Gaertner et al. 2016).

Achieving control of the most important species

Almost two thirds of available funds were spent on the control of trees and shrubs in the genus *Acacia*. These species spread by means of soil-stored seeds primarily down rivers, streams and drainage lines, or through soil movement (e.g. when used in road building or maintenance). As a result, they tend to be in more accessible areas when compared, for example, to trees and shrubs in the genera *Hakea* and *Pinus*, that have winged seeds and are spread over considerable distances by wind. As a result, *Hakea* and *Pinus* arguably pose a far greater threat in the long term than *Acacia* trees as they will ultimately dominate more inaccessible areas. It also needs to be considered that the control of *Acacia* species is considerably assisted by biological control, whereas no biological control agents have yet been released against *Pinus* species. This suggests that a greater proportion of available funding should be used to contain *Pinus*

species, given the greater threat that they pose to the long-term integrity of fynbos ecosystems.

3.2. Management outcomes.

Setting goals for management outcomes

Reducing the impacts of invasive species populations by eradication or locally extirpating them or reducing them to levels where they can sustainably be maintained in perpetuity (e.g. Fill et al. 2017; van Rensburg et al. 2017) are desirable management outcomes. These goals were not explicitly stated in most management plans that we considered here. One of the problems would be that achieving a maintenance level is not possible within the time frame of management plans (10 years). Managers tasked with achieving such a goal within a relatively short period would be set up to fail. Thus, while Target 6's requirement that invasive alien species should be controlled has clearly been addressed in the CFR, there is still a need for more explicit, and achievable, targets to guide ongoing management.

Besides reducing populations of alien species, the ultimate outcome in protected areas should be to restore previously invaded ecosystems to their original composition, structure and functionality. There is evidence that active restoration of invaded ecosystems may be necessary after the removal of invasive species. For example, Fill et al. (2017) investigated the recovery of native vegetation in the catchment of the Berg River following the clearing of alien *Pinus* and *Acacia* species. They reported that the mean number of native species, and total projected canopy cover on 50 m² plots was lower in cleared than in comparable reference sites with pristine native vegetation (21 vs 32 species/plot, i.e. a recovery of 70% of native species after clearing). In the eastern parts of the CFR, Baard et al. (2023) reported relatively good passive recovery of native vegetation following the removal of pine plantations and found that cleared plantations supported 91% of the native species found in adjacent (unplanted) fynbos. They concluded that the restoration potential of the eastern fynbos (with a comparatively higher proportion of grasses) was superior to that previously documented in western proteoid fynbos. However, the full complement of species had not yet re-established. Where invasive alien freshwater fish have been locally extirpated, this was also

not sufficient for full recovery of all indigenous fish species, and it was recommended that additional conservation management strategies would be needed to secure the population stability and persistence of endangered fishes (Castañeda et al. 2020).

Active restoration interventions might, in some cases, be feasible, but the cost of fully restoring ecosystem structure, functioning, and composition in highly degraded ecosystems has rarely been deemed economically justifiable in South Africa (Holmes et al. 2020; van Wilgen et al. 2022). Generally, government-supported control operations have not included restoration efforts, at least in part because there is little or no funding for implementing active restoration projects at the necessary scale—most sites are left for passive restoration (van Wilgen et al. 2022). Nonetheless, the intended outcomes of alien species control need to be clearly outlined in management plans in terms of what would be desirable and achievable both for reducing alien species and for restoring ecosystem composition and functioning.

Achieving control of alien freshwater fish species

The invasive alien vertebrate species most frequently listed as dominant problems in the management plans for the CFR's PAs are freshwater fish (Online Resource S1), where attempts to control them have been very limited. This is because their management is both difficult and controversial. There has been strong resistance to the control of trout (*Oncorhynchus mykiss* and *Salmo trutta*) and bass (*Micropterus* species) from sport anglers (Woodford et al. 2016). Managing freshwater fish using piscicides is also only possible in certain situations where recovery of native species was possible (e.g. Castañeda et al. 2020; Weyl et al. 2014). Manual removal of fish is usually ineffective. For example, concerted attempts to control common carp (*Cyprinus carpio*) in Groenvlei Lake using netting and bow hunting over 38 months was ineffective because it only removed an estimated 11% of the population (Zengeya and Wilson 2023). The only effective way to prevent escalation of these problems would be to prevent introduction of alien fish into catchment areas where the alien species does not yet occur. At present, there are no obvious solutions given the prevailing disagreements on how to manage the problem (Woodford et al. 2016).

Recommended actions

Increasing funding

Funding for the management of biological invasions in the CFR is insufficient and declining (Stafford et al 2018; van Wilgen et al. 1997), despite evidence of the substantial returns on investment that would arise from effective control (de Lange and van Wilgen 2010; Stafford et al. 2017; van Wilgen et al. 1997). Potentially, there are additional or alternative approaches to securing adequate funding that could improve the situation. The Greater Cape Town Water Fund is a welcome development in this regard and could potentially be expanded to other areas. Payments for ecosystem services could also potentially be used to raise funds for alien plant control. This has been recognised for a long time (van Wilgen et al. 1996; Turpie et al. 2008) but has not yet been implemented and offers very promising prospects. The situation regarding both SANParks and CapeNature would also be considerably alleviated if they could be directly funded instead of having to apply for funding from the national department (and this would also bring about a saving of 22.6% that is currently incurred through overheads to Working for Water). Increasing, streamlining and diversifying sources of funding should be a priority action, given the attractive returns on investment that it would deliver.

Integration with fire

The frequent and widespread occurrence of unplanned wildfires in the PAs of the CFR further complicates the management of invasive species. Unplanned wildfires accounted for between 68 and 96% of the area burnt in 10 PAs in the CFR over 35 years (van Wilgen et al. 2010), and they trigger the spread and germination of seeds of alien plants, notably *Acacia*, *Pinus* and *Hakea* species. Following fire, the seedlings of alien plants need to be removed while they are still small to avoid the rapid escalation of effort and cost that would be needed if they were left to grow, and this in turn requires other scheduled control operations to be postponed to free up resources. Short-term management plans often must be revised, and management therefore needs to be agile, and able to re-focus its efforts

rapidly. This is difficult in the current bureaucratic and inflexible environment in which PA managers must operate.

Although alien plant control programs were integrated with a schedule of prescribed burning in the CFR in the late twentieth century (Richardson et al. 1994), they have more recently proved challenging to implement due to seasonal restrictions on burning (i.e. the ecologically optimum season for burning is also when fire danger is highest, van Wilgen 2013). Effective use of fire would require burning sites where *Pinus* or *Hakea* trees have been felled, to kill seedlings before they can mature. In addition, management needs to be flexible and agile enough to be able to capitalise on unplanned wildfires. Following such events, it would be important to control post-fire regrowth early, before plants reach larger sizes when the costs of control would be orders of magnitude greater. To increase the opportunities for more use of fire, the seasonal restrictions on burning outside of the ecologically optimal season could also be considered in some cases. Deciding on such trade-offs would be based on which option (i.e. restricting fires to certain seasons or not) would deliver the best outcome for conserving biodiversity (van Wilgen et al. 2016b).

More effective use of biological control

Given that biological control has contributed to substantially to the management of invasive alien plants in the CFR, more opportunities for expanding these successes should be actively sought. For example, it has to date not been possible to obtain permission for the release of biological control agents against *Pinus* species due to concerns raised by the commercial forest industry (Hoffmann et al. 2011). Discussions have subsequently been held with the forest industry to allay fears about the potential impacts of the biological control agent, and the project may soon be re-instated (G. Martin, Centre for Biological Control, personal communication). Zachariades et al. (2017) have argued strongly for increasing expenditure on biological control research, development and implementation, but government funding has been suspended. This should be given priority attention.

Improved monitoring of outcomes

It would be desirable to develop and adopt a standard approach to monitoring the effectiveness of control interventions in terms of their outcomes. A start has been made with this in the area where invasive alien trees are managed by the Greater Cape Town Water Fund. The fund has set aside 1.5% of their budget for monitoring which aims, *inter alia*, to assess the effects of clearing on water runoff and the recovery of biodiversity following clearing, as well as changes in the cover and density of invasive trees. This approach needs to be more widely implemented.

Conclusions

Considerable progress has been made with respect to implementing a program to control invasive alien species in the PAs of the CFR, in line with Target 6 of the Kunming-Montreal Global Biodiversity Framework. A robust set of regulations have been put in place to enable governance, and adequate management plans have been developed for PAs. There has clearly been encouraging progress in some relatively well-funded PAs and with some species due to biological control, but in others the invasions continue to spread. Despite generous funding being made available, it is insufficient to comprehensively address the problem, and the funding is unequally distributed and declining. New sources of funding will be needed, and some progress has already been made in this regard. The absence of a program to monitor the outcomes of interventions remains a significant barrier to improving our understanding and to being able to practice effective adaptive management. Target 6 provides a very broad outline of what it is that governments are expected to do, but local interventions aligned with the achievement of Target 6 need to be made more explicit and realistic to meet the needs and circumstances of different local situations such as found in the PAs of the CFR.

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Author contributions BWvW initiated the assessment, analysed and interpreted the data, and wrote the paper. NSC sourced data on money spent per protected area per year, supported by AAT and AW. AAT and NJvW provided lists of alien species present in protected areas. LS provided estimates of money spent by the Greater Cape Town Water Fund, as well as descriptions of the Fund's monitoring program. BWvW, CC, NSC, KE, AAT and NJvW participated in a workshop at which the findings were presented and debated. All authors reviewed drafts of the paper and approved the final version before submission.

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Data availability This assessment is based on (1) the records of the Working for Water programme which are available at <https://sites.google.com/site/wfwplanning>; (2) records of the Greater Cape Town Water Fund which are available at https://public.tableau.com/app/profile/waterfunds/viz/GCTWF_DSSv1/PublicDSS; and (3) successive reports on the status of biological invasions and their management in South Africa which are available at <https://dx.doi.org/https://doi.org/10.5281/zenodo.8217182> and <http://dx.doi.org/https://doi.org/10.5281/zenodo.3947817>, with links to supplementary material and appendices.

Declarations

Conflict of interest The authors declare no conflicts or competing interests.

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