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Assessing the effectiveness of invasive alien plant management in a large fynbos protected area

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Background: Concern has been expressed about the effectiveness of invasive alien plant (IAP) control operations carried out by Working for Water (WfW). South African legislation now also requires reporting on the effectiveness of IAP management interventions.

Objectives: We assessed the effectiveness of IAP management practices in a large fynbos protected area, the Garden Route National Park, South Africa.

Methods: We undertook field surveys of pre-clearing IAP composition and the quality of treatments applied by WfW during 2012–2015 in 103 management units, covering 4280 ha. We furthermore assessed WfW data for evidence of change in IAP cover after successive treatments, and adherence to industry norms.

Results: Despite the development of detailed management plans, implementation was poorly aligned with plans. The quality of many treatments was inadequate, with work done to standard in only 23% of the assessed area. Problems encountered included (1) a complete absence of treatment application despite the payment of contractors (33% of assessed area); (2) treatments not being comprehensive in that select areas (38%), IAP species (11%) or age classes (8%) were untreated; (3) wrong choice of treatment method (9%); and (4) treatments not applied to standard (7%). Accordingly, successive follow-up treatments largely did not reduce the cover of IAPs. Inaccurate (or lack of) infield estimation of IAP cover prior to contract generation resulted in erroneous estimation of effort required and expenditure disparate with WfW norms.

Conclusions: We advocate rigorous, compulsory, infield assessment of IAP cover prior to contract allocation and assessment of the quality of treatments applied prior to contractors' payment. This should improve the efficiency of control operations and enable tracking of both the state of invasions and effectiveness of management.

Introduction

Invasive alien plants (IAPs) are globally considered to be a significant threat to biodiversity conservation and the sustained delivery of ecosystem services (Dukes & Mooney 1999; Vilà et al. 2011; Vitousek et al. 1996; see also Clusella-Trullas & Garcia 2017). Accordingly, considerable resources are expended in attempts to address this problem (Van Wilgen et al. 2012). South Africa has one of the largest government-funded programmes in the world aimed at managing IAPs, that is, the Working for Water Programme (WfW) (Van Wilgen et al. 2012). This programme was initiated in 1995 with the dual objectives of (1) clearing IAPs to increase water delivery and improve ecological integrity and (2) job creation to alleviate poverty (Van Wilgen, Le Maitre & Cowling 1998).

Strategic assessments of WfW have repeatedly expressed concern about the efficiency of the programme at various levels of operation (Common Ground 2003; Van Wilgen et al. 2012; Van Wilgen & Wannenburgh 2016). Recommendations put forward by these assessments included the prioritisation of IAP species and areas for management (i.e. better planning) (Roura-Pascual et al. 2009), improved coordination, efficiency and professionalism of interventions, and the development and implementation of a monitoring programme (Van Wilgen et al. 2012). National legislation under the Alien and Invasive Species Regulations of the National Environmental Management Biodiversity Act (Act 10 of 2004) requires regular (every 3 years) reporting on the status and impact of invasions, and the effectiveness of management and policy interventions (Wilson et al. 2017).

Globally, inadequate attention has been paid to assessing the effectiveness of control interventions (Kettenring & Adams 2011). In South Africa, studies that have evaluated particular aspects of IAP

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control operations include assessments of (1) the efficiency of WfW in the Cape Floristic Region by determining what would have happened had the programme not intervened (using counterfactuals) (McConnachie et al. 2016), (2) cost-benefit of IAP control in terms of water gains (Hosking & Du Preez 1999, 2002), (3) the effects of clearing treatments on IAP seedbanks (Holmes et al. 1987) and recovery of indigenous vegetation (Holmes & Marais 2000; Parker-Allie et al. 2004), (4) the use of adaptive management in IAP management in national parks (Loftus 2013) and (5) the cost-efficiency of WfW at biome scale (Van Wilgen et al. 2012) and project (local) scale (McConnachie et al. 2012). The latter study compared records of IAP cover before and after multiple control treatments during a defined study period to determine whether treatments effected a reduction in IAP cover. To our knowledge, no study has undertaken targeted assessments of treatment efficacy through field observations.

We report here on a case study in a large protected area of the Cape Floristic Region, the Garden Route National Park (GRNP), where we assessed the efficiency of WfW's IAP management practices in the field. Parts of the GRNP have a long history of WfW operations, while comprehensive, strategic planning, prioritisation and improved monitoring have only recently been initiated. In particular, we considered the following aspects:

(1) the alignment of implementation with management plans
(2) the effectiveness of alien plant clearing practices in the field
(3) the relationships between IAP species, age classes and cover, and treatment effort.

These investigations allowed us to identify challenges experienced by WfW projects during different stages of implementation (planning, costing and execution) and to produce recommendations towards improving the effectiveness of IAP management practices, which may be widely applicable.

Methods

Study area

The study area is the GRNP (33.80°S 22.50°E – 34.15°S 24.20°E), situated along the southern Cape coast of South Africa between the Indian Ocean in the south and the watershed of the Outeniqua and Tsitsikamma Mountains in the north. The park extends over 152 500 ha of which ca. 78 000 ha comprise fire-prone fynbos shrublands and ca. 41 500 ha comprise Afrotemperate forest. A more detailed biophysical description of the park is given by Kraaij, Cowling and Van Wilgen (2011), and an account of the alien flora is given by Baard and Kraaij (2014). The GRNP was only recently (2009) proclaimed, and the proclamation was preceded by approximately 20 years of neglect in terms of fire and IAP management in most of the mountain catchment areas that now form a part of the GRNP (Kraaij, Cowling & Van Wilgen 2011). More than 244 species of alien plants occur in the park (Baard & Kraaij 2014), the most common invasive genera being *Pinus* and *Hakea*, both estimated to occur over > 90% of the park's fynbos vegetation at various densities, and *Acacia* over almost 30% (Van Wilgen et al. 2016). IAPs are accordingly considered the leading ecological threat to the GRNP (SANParks 2010), with considerable expenditure (approximately ZAR 20 million, ~US $1.5 million in 2015) allocated annually to IAP clearing operations undertaken by WfW (SANParks 2010).

Procedures followed in IAP management at park/project level

WfW has been involved in IAP control in the area of the GRNP (prior to proclamation) since the programme's inception in 1995 albeit initially at a small scale (Hosking & Du Preez 1999). Up until 2013, the selection of areas to treat during any particular year largely did not follow a strategic plan or prioritisation process, and the tendency was to mostly do follow-up treatments in areas that had been previously treated. This trend partially stemmed from a prominent, and financially rational, drive in the WfW programme to maintain areas that have been worked previously (Loftus 2013), but also from a general lack of a strategy to guide its operations and the selection of projects (Common Ground 2003; Van Wilgen & Wannenburgh 2016). At project operational level, it is furthermore convenient to keep working in accessible areas and under familiar conditions.

Since 2014/2015, the scientific services department of South African National Parks (in consultation with park and WfW staff) developed a strategic medium-term plan for clearing IAPs from the GRNP. This plan was based on the principles of sound prioritisation of area and IAP species (Forsyth et al. 2012; Nel et al. 2004), accurate costing of clearing requirements as per WfW norms (Neethling & Shuttleworth 2013), alignment of treatment approaches and practices with ecological and biological attributes of systems and species (Table 1), and monitoring of changes in IAP distribution and cover over time (Working for Water Programme 2003), *inter alia* to monitor the success of control operations. There was general acceptance of this plan by park and WfW staff alike, and mutual agreement to translate the strategic plan into annual plans of operation (APOs) (which are formulated by WfW project management staff) and to implement these plans.

We briefly outline the procedures involved in implementation of WfW projects by implementing agents, including SANParks, but more detail is provided by Loftus (2013). Annual project level funding is based primarily on historical allocations, but has grown steadily in the GRNP since 2010. Annual funding requirements per project are outlined in an APO, and once funding has been secured, the APO is approved and the operational targets (in terms of expenditure, hectares to be cleared and effort required expressed as person days) are captured into the WfW information management system. Prior to awarding contracts to service providers, WfW project managers are required to do infield inspections in each management unit, collecting data on IAP species present, their cover, age classes and appropriate treatment methods.

TABLE 1: Principles associated with a strategic medium-term plan to control invasive alien plants in extensive and often remote fynbos areas of the Garden Route National Park.

Principle	Rationale
Fynbos at post-fire ages of 1–2 years should be given first priority.	- At 1–2 years after fire, treatment occurs before reproductive maturity of most IAPs and, thus, largely prevents seed set. - 2 years allows for some seedling mortality because of self-thinning (Geldenhuys 2004). - Young vegetation is readily accessible and treatment methods are cheaper, thus reducing the cost.
Fynbos at post-fire ages of 3–10 years are given second priority.	- At 3–10 years post-fire, vegetation is still reasonably accessible, reducing the cost. - Some alien species may have reached reproductive maturity, but seed banks will be relatively smaller than in older vegetation.
Follow-up treatments should take place at 4-year intervals where pines are the dominant invaders.	- Pines are the dominant invaders in large tracts of mountain fynbos (Van Wilgen et al. 2016) and 4-year intervals should ensure that treatment occurs before regrowth (seedlings) reaches reproductive maturity [juvenile periods in *Pinus pinaster* are 6 years and in *Pinus radiata* 5 years, Richardson, Cowling and Le Maitre (1990)]. - 4 years after the previous treatment, the regrowth is still small enough that simple treatment methods and equipment can be used.
Follow-up treatments should take place at 2-year intervals in areas where acacias or other re-sprouters with large persistent soil-stored seed banks are the dominant invaders (in addition to ensuring that biological control agents are present, if available).	- 2 years allows for some seedling mortality because of self-thinning (Geldenhuys 2004). - After 2 years, seedlings are still small enough and total biomass low enough that the required treatment methods are simple and relatively cheap; biomass does not yet cause a high fuel load and fire risk, neither does it have to be removed from riparian zones. - Although many invasive acacias reach reproductive maturity within a year, they usually do not produce large numbers of seeds at an early age, that is < 2 years (Milton & Hall 1981). - Follow-up intervals of < 2 years (albeit potentially more effective to treat acacias) would result in less resources being available for clearing of extensive catchment areas with low-cover pine invasions (Van Wilgen et al. 2016).
Fell mature pines with chainsaws instead of ringbarking, as an initial clearing treatment (at densities where felled biomass does not create excessive fuel loads).	- Ringbarking facilitates wind dispersal of pine seeds from slow-dying, standing trees, whereas seeds do not disperse from felled trees. - Felling results in 100% mortality (in the non-sprouting species, *P. pinaster* and *P. radiata*, common to the study area), as opposed to ringbarking 20% – 90% mortality (Pers. Obs.). - Felling enables rapid verification of the extent and the quality of work done after treatment application, whereas it is difficult to assess whether ringbarking has been done properly, especially in inaccessible areas. - Felling (unlike dead standing trees) enhances landscape aesthetics (Barendse et al. 2016).
Prioritising areas where IAPs occur at low levels of cover.	- Provides the best return for investment (Van Wilgen et al. 2016).

IAP, invasive alien plant.

Source: South African National Parks, unpublished information

Theoretically, cover can exceed 100% if different IAP species or age classes form multiple strata at high cover classes, although it seldom happens in the GRNP. These data are then cross-referenced with the APO prior to contracts being awarded. Contracts for work are generated through the WfW information system, and the effort requirement for each contract is automatically calculated using the WfW norms (Neethling & Shuttleworth 2013). Project managers then estimate the cost of each contract based on the allocated effort (person days). WfW-registered contractors tender for the contracts through a bidding system, and contracts are awarded based on these tenders. Protocol requires that a minimum of three joint site inspections per contract are undertaken by the WfW project manager and the contractor prior to the start of the contract, during execution, and before contracts are signed off for payment. Once a contract has been signed off for payment, the completed contract document (which includes time-sheets reflecting actual days worked on the contract, start and end dates, as well as actual expenses) is captured into the WfW information system.

Data collection and analysis

We restricted our analyses to the areas covered with fynbos vegetation within the GRNP, and to work carried out by WfW between 2004 and 2015 with an emphasis on the 2014/2015 financial year (1 April 2014 to 31 March 2015). Our unit of assessment was the management unit as spatially delineated by WfW and reported on as cases in their information system [see Working for Water Programme (2003) and Loftus (2013) for details of information recorded in this information system]. 'Cover' throughout this paper refers to the percentage projected canopy cover of IAPs, which is recorded as 'density' by WfW in their information system, and theoretically determined by WfW from stem counts of IAPs and then converted to a percentage cover value (Working for Water Programme 2003).

To assess whether implementation was aligned with the strategic medium-term plan, we compared, in terms of geographic overlap and total extent, the areas that were planned to be treated during 2014/2015 with those included in the 2014/2015 APO. We furthermore compared the strategic medium-term plan and APO with records of areas cleared during 2014/2015 according to the WfW information system.

To evaluate the effectiveness of clearing practices, we inspected 103 management units in the field (covering 4280 ha worked by WfW during 2012–2015) where we (1) estimated pre-treatment cover and size classes of IAP species and (2) assessed the quality of IAP management treatments. Field surveys were mostly done within 6 months after the execution of control treatments, which then provided information on both these aspects (as ringbarked and felled trees and shrubs remain *in situ* enabling estimation of pre-treatment cover). We compared our field estimates of pre-treatment IAP cover with those estimated by WfW prior to contract allocation of that particular treatment in the same 103 management units using a Wilcoxon matched pairs test. To assess the quality of IAP treatment practices, we recorded for each management unit the degree to which the treatments were satisfactorily carried out, and if not, how the treatments deviated from acceptable standards. We subsequently classified these deviations by type (Table 2) and calculated their rates of incidence, both in terms of the number of management units affected and by the areas affected.

We also assessed whether IAP cover recorded in WfW's information system decreased with successive follow-up treatments. For these analyses, we considered the complete

TABLE 2: Types of deviations from acceptable standards of treatment application, and their rates of incidence in terms of the number of management units affected, and by area. A total of 103 management units, and 4280 ha, were assessed. More than one deviation type could pertain to a management unit.

Type of deviation	Incidence (% of number of units examined)	Incidence (% of total area examined)
Inaccurate estimation of alien plant cover, causing inaccurate allocation of person days and cost	25 on par; 5 underestimated; 70 overestimated	40 on par; 7 underestimated; 53 overestimated
Incorrect identification of dominant species (often listing re-sprouters, requiring greater treatment effort, instead of non-sprouters)	22	36
No evidence of work done during last treatment – Aliens present were not cleared, yet contractor paid – No aliens present, yet contract generated and contractor paid	44	33
Some individuals of target species or part of management unit not treated	34	38
Some age groups of target species not treated (e.g. adults treated, saplings untreated)	5	8
Some species not treated (e.g. *Pinus* treated, *Hakea* untreated)	11	11
Wrong choice of treatment method (e.g. ringbarking of trees < 10 cm diameter; ringbarked AND felled trees; ringbarking of dead trees)	11	9
Treatment not applied to standard – Ringbarked strip too narrow – Ringbarked on only one (the most visible) side of the tree – Re-sprouting plants felled but no herbicide applied, or wrong choice/ concentration of herbicide	7	7
Work done well	15	23

treatment history (spanning the period 2004–2015) of management units ($n = 764$) that received their last treatment during 2012–2015. Most management units received multiple treatments (mean = 5, maximum = 12); we discarded data for treatments beyond the seventh follow-up treatment, as there were too few cases for meaningful analysis. We assessed the efficiency of treatments by comparing change in cover between successive treatments on the same site. Cover was recorded prior to each treatment, and we expressed the treatment effect as the ratio of cover before a specific treatment to the cover before the prior treatment; this measure we refer to as 'proportional change', where ratios of < 1 represent reductions in cover, and ratios of > 1 represent increases in cover. We also calculated 'absolute change' as the difference between the cover before a specific treatment and the cover before the prior treatment, where negative values represent reductions in cover and positive values represent increases in cover. We calculated these measures for each treatment (up until the seventh follow-up treatment) within each management unit (total of 2738 treatments on 764 management units), and thereafter, calculated mean and median change in cover achieved per treatment cycle across all management units.

The large and persistent soil-stored seed banks of the dominant *Acacia* species in the study area continue to fuel vigorous recruitment even after several successive clearing treatments (Holmes et al. 1987; Milton & Hall 1981; Richardson & Kluge 2008). Most of the other common woody IAP taxa (*Pinus* and *Hakea*) do not have persistent soil-stored seed banks, and recruitment in these taxa should consequently be much less after successive treatments, provided seeds are not released from cones onto open ground such as post-fire (Macdonald, Clark & Taylor 1989). Given this differential response to treatment, we expected a much slower decrease in the cover of *Acacia* compared with that of *Pinus* and *Hakea* after successive treatments. We tested whether the two groups (differentiated based on indication of dominant species per management unit in the WfW information system) differed in terms of change in cover following successive follow-up treatments (using Mann–Whitney *U*-test).

To assess whether allocation of effort to treatments was aligned with the dominant IAP species, age classes and cover, we compared the relationship between these variables with the WfW norms (Neethling & Shuttleworth 2013). For this comparison, we limited our analysis to, and distinguished between, *Acacia* and *Pinus* or *Hakea*, as differential norms pertain to these groups (Neethling & Shuttleworth 2013). *Acacia* is more costly to treat than *Pinus* or *Hakea* as the former requires herbicide application to prevent re-sprouting. We used 'modelled person days' (which is the number of person days allocated at the time of contract generation to the treatment of a management unit) in the WfW information system as a measure of effort allocated (effort is a better measure than cost as it is not subject to inflation) and expressed that per unit area (i.e. person days per hectare). Our dataset comprised 2092 treatments on 738 management units. The relationship between effort (person days per hectare) and IAP cover was established by means of regression for *Acacia* and *Pinus* or *Hakea* (differentiated based on indications in the WfW information system of the dominant species treated), and the residuals compared by a *t*-test to determine whether the effort-cover relationship differed between the two groups. All statistical analyses were performed in Statistica (version 13, 1984–2015, Dell Inc.).

Results

Alignment of implementation with planning

The work carried out during the 2014/2015 financial year deviated to a large degree from the agreed priorities in the medium-term strategic plan. Only 47% of the area on the strategic medium-term plan for that year was carried forward to the APO. Furthermore, there was a failure to complete all of the work scheduled in the APO. Only 19% of the area on the strategic plan for 2014/2015 and 37% of the area on the APO were actually carried out (see Appendix 1), but not necessarily treated to standard (see subsequent results). In addition, work was carried out in non-priority areas that were not included in either the medium-term strategic plan or the APO, equivalent in size to 12% of the annual plan.

Quality of work and discrepancies in cover estimates

We found evidence for widespread ineffective treatment of IAPs in the field. Field surveys of recently treated areas (103 management units, total area 4280 ha) showed that in 85% of the assessed units (77% of the assessed area), work was not done to standard (Table 2). Various types of problems contributed to this finding, including an apparent complete absence of work despite the payment of contractors, partial work done, not all the IAP species or age classes present being treated, wrong choice of treatment method and treatments not being applied to standard.

We found evidence that cover was regularly overestimated prior to the awarding of contracts. The IAP cover estimates recorded by WfW (mean 54.8% ± SD 56.5%; median 32.5%) prior to contract allocation were more than double ($Z = 7.06$, $p < 0.001$, df = 100) those of our estimates from field surveys (13.8% ± 16.9%; 8.0%). WfW estimates also exceeded 100% in 15% of cases (Figure 1). The frequency distribution of IAP cover recorded by WfW (in 764 management units treated between 2012 and 2015) shows that more than half (54%) of cover estimates were > 25%, and 17% exceeded 100% (Figure 2).

We also found, contrary to expectation, that repeated treatments of management units more frequently led to increases, rather than decreases, in cover. In addition, and also contrary to expectation, we found no significant difference ($Z = -1.11$, $p = 0.27$, df = 1988) between *Acacia* (where increases in cover may potentially be explained by germination from large and persistent soil seed banks) and other IAP genera (where there are no persistent seed banks to fuel continuous germination and regrowth). For this reason, we present pooled data for all IAP taxa in Figure 3. Due to large numbers of extreme outliers (positively skewed data; note the respective sizes of 75 percentiles vs. 25 percentiles in Figure 3, and outliers in Figure 3b), means and medians presented varied results. We present medians which modulate the influence of outliers, although the substantial influence of outliers as revealed in means, should also be noted. Across all treatments (irrespective of follow-up treatment cycle), the median absolute change in cover was 0, while the mean showed an increase in cover of 7%. When considering proportional change in IAP cover resulting from all treatments, the median was 0.94 (a slight reduction), while the mean was an eightfold increase in cover. The only treatments resulting in reductions in the median cover were treatments 0 (initial), 1 and 4 (Figure 3), while none of the treatments led to reductions in mean cover. Contrary to expectation, both measures of change in cover furthermore showed a trend of rising increases in IAP cover as more follow-up treatment cycles were applied.

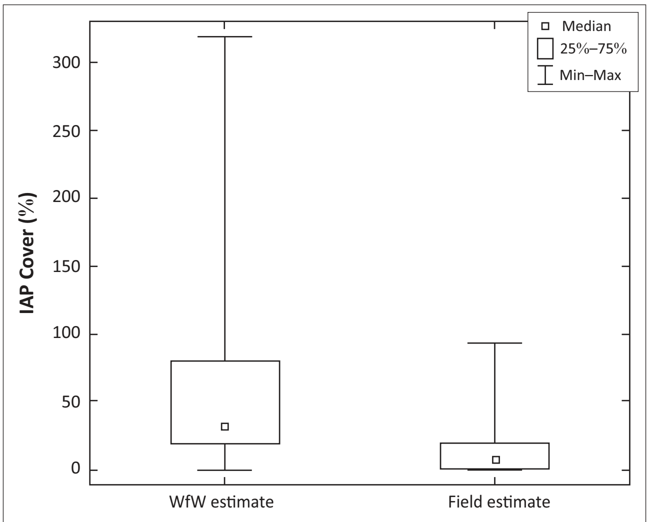


FIGURE 1: Cover (%) of IAPs as estimated by Working for Water prior to contract allocation and during our field surveys in the same 103 management units (total area 4280 ha).

Deviation of actual expended effort from norms

The effort required to control IAPs increased with IAP cover ($F_{1,2090} = 2781$, $p < 0.001$, $R^2 = 0.57$), but a large proportion of the variation in the data was not explained by the regression model (Figure 4). In addition, and contrary to expectation, there was no difference in this relationship between cover and effort for *Acacia* and *Pinus* or *Hakea* ($t = 1.24$, $p = 0.21$, df = 1593). A large difference should be expected, as the costs of clearing *Acacia* are much higher than the costs of clearing *Pinus* or *Hakea* at comparable levels of cover. There was large variation in the data with cover ranging up to 318% and effort up to 93 person days per hectare, also revealing substantial deviation from (both above and below) the norms. Given that these data do not include treatments undertaken by specialised high-altitude teams (which are very costly), high effort allocations may only be accounted for in a limited number of cases where remoteness and difficult terrain could have demanded increased effort of up to 150% of the norms (Van Wilgen et al. 2016). Yet, three- to five fold inflations of effort compared with the norms were common.

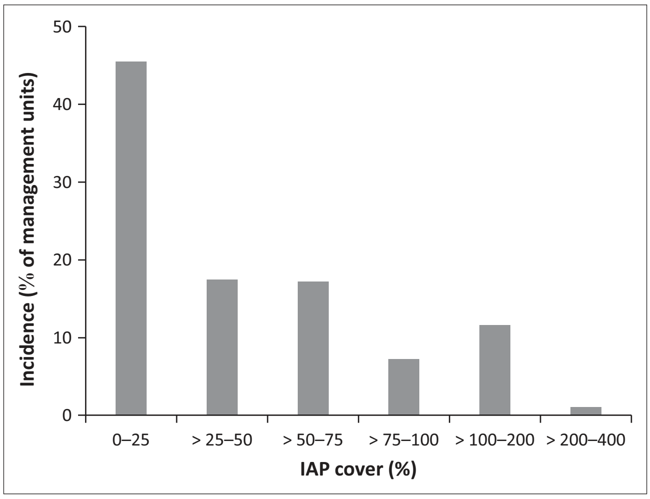


FIGURE 2: Frequency distribution of cover (%) of IAPs estimated by WfW in 764 management units last treated between 2012 and 2015 (total area 21 760 ha).

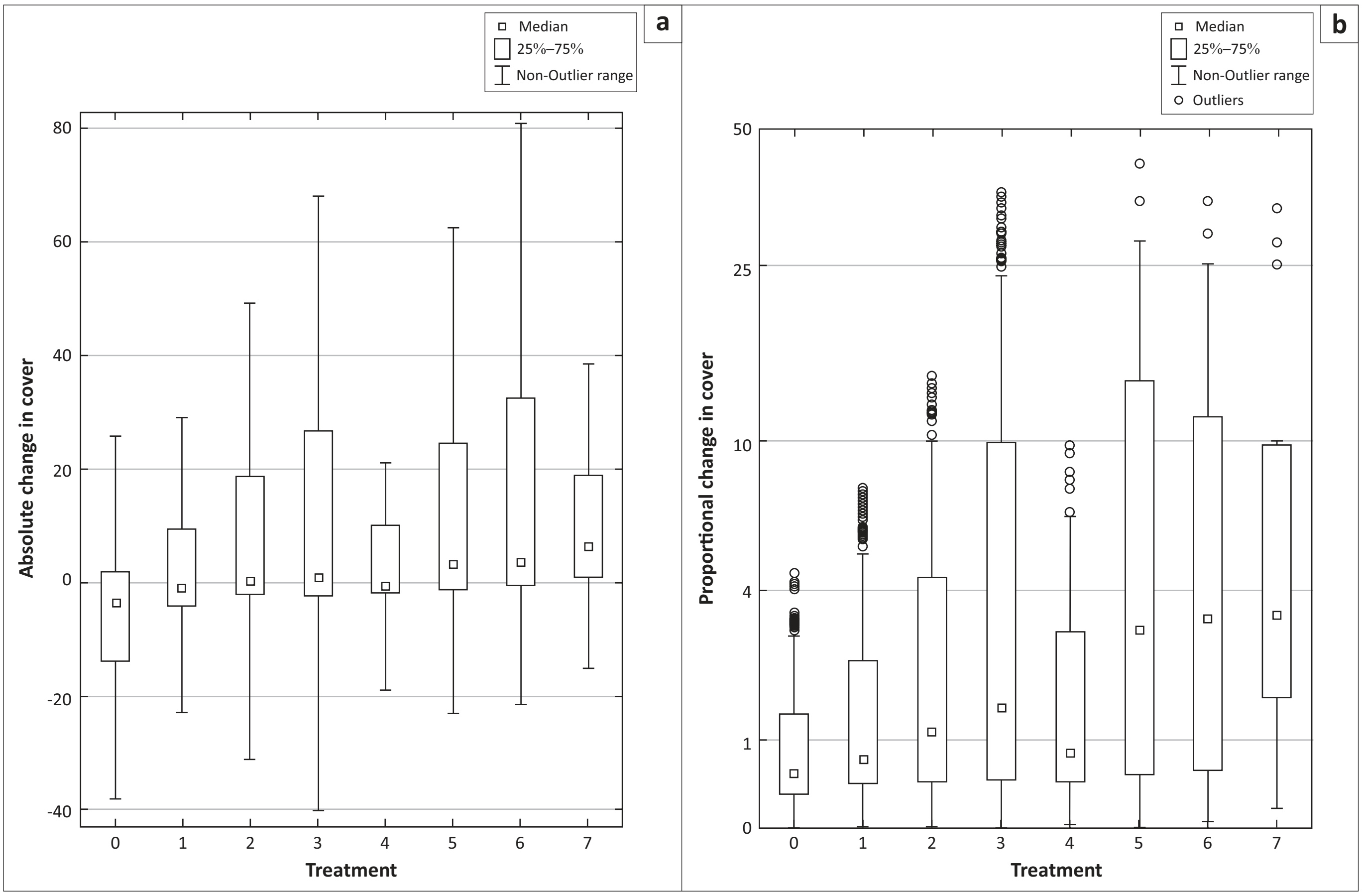
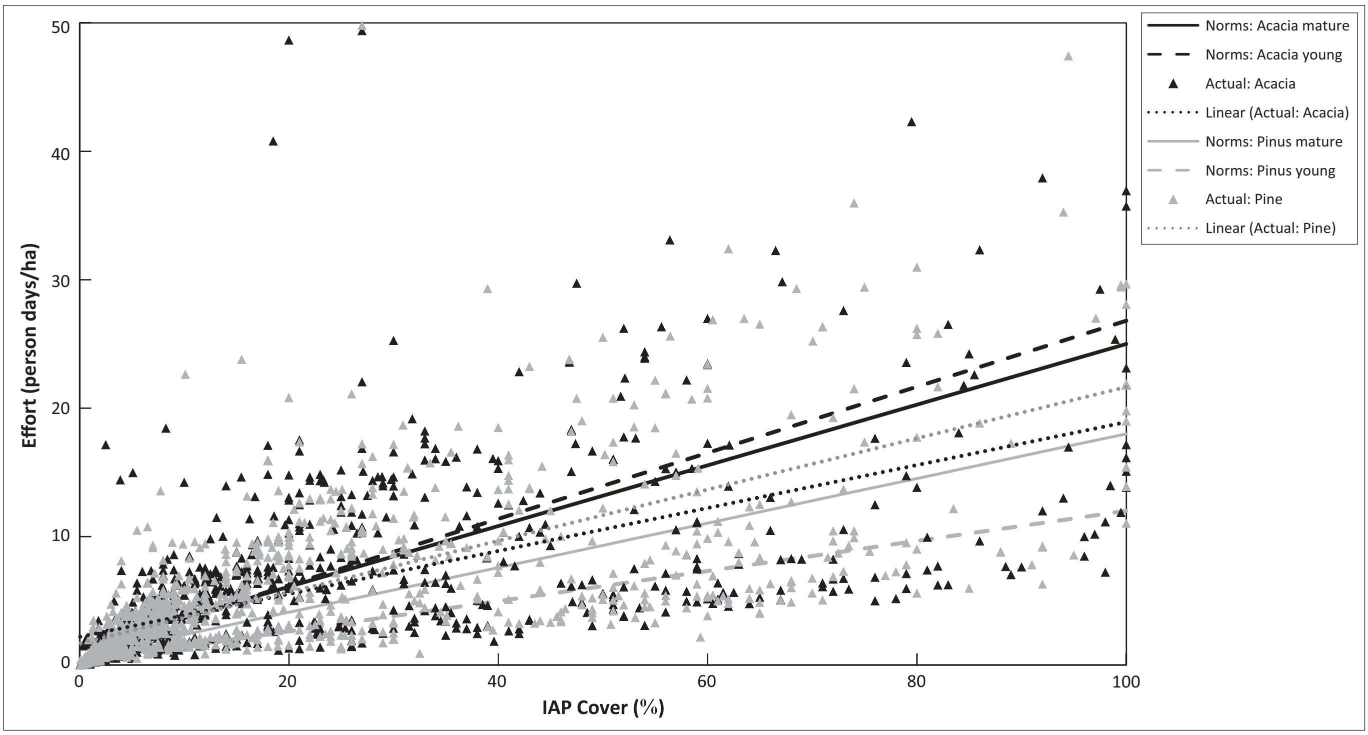


FIGURE 3: (a) Absolute and (b) proportional change in cover of IAPs effected by successive follow-up treatments, as recorded by Working for Water in 764 management units (21 760 ha). Absolute change was calculated as the difference between cover before a specific treatment and cover before the prior treatment; proportional change was calculated as the ratio of cover before a specific treatment to the cover before the prior treatment. Treatment = 0 represents the effect of the initial treatment. Outliers are not shown in (a) to enhance figure clarity, while the y-axis in (b) is spaced on a log-scale to accommodate outliers.



IAP, invasive alien plant.

FIGURE 4: The relationship between actual allocated treatment effort (expressed as person days per hectare) and IAP cover estimates, compared to Working for Water norms. Distinction is made between *Acacia vs. Pinus* or *Hakea* as dominant invaders. Outliers were removed to enhance figure clarity.

Discussion

A lack of planning had previously been identified as a factor reducing the effectiveness of control (Van Wilgen et al. 2012). To address this, the GRNP developed guidelines for the prioritisation and planning of control operations. To date, there has been a failure to implement these plans. To our knowledge, this study presents a first targeted assessment, largely based on field observations, of the effectiveness of IAP management interventions at WfW project level. We critically evaluated the work flow and procedures employed during the implementation of WfW projects, which allowed us to identify the challenges experienced by such projects during different stages of implementation (planning, costing and execution) and to make recommendations towards improving the efficiency of IAP management practices.

Effectiveness of IAP management interventions

The GRNP proved exemplary in having heeded the calls (Van Wilgen et al. 2012) for prioritisation of species and areas for treatment, and better planning and coordination. A strategic medium-term plan, based on sound ecological principles, was developed and agreed to by park- and WfW management authorities. However, there appeared to be major challenges with implementation and coordination, with < 20% and < 40% achievement of annual area targets according to the medium-term and annual plans, respectively, as well as considerable effort expended in areas not aligned with the plans. Apart from substantial underachievement of area targets, this furthermore resulted in disjointed, and thus less efficient, allocation of treatment effort in space and time (Roura-Pascual et al. 2009).

Our assessments of the quality of infield treatment applications revealed equally disappointing results with no evidence of work done over a third of the assessed area, and deviations from acceptable standards of treatment application occurring over an additional 44% of the area. Treatments have, thus, been applied to standard in less than 15% of the assessed units. Our findings are similar to those of McConnachie et al. (2012) in the Krom and Kouga catchments of the Eastern Cape, where 'many sites [24% of sites in Kouga and 4% in Krom] that were recorded as treated in the information system were in fact never treated'. The poor quality of treatment applications observed during our field surveys can also partially explain the lack of a consistent decline in IAP cover after successive follow-up treatments evident in the WfW information system (Figure 3). Apart from a complete absence of work (despite payment), a diverse array of problem types were apparent in our study (Table 2). Jointly, these different types of problems suggest that ignorance, inappropriate equipment, inadequate skills and training, as well as deliberate negligence and even fraudulent behaviour could have contributed to the poor standard of treatment application. Such diverse issues are expected to require considerable and varied interventions to try to correct.

Overall, less than 10% of the strategic medium-term plan that was designed to 'effectively' reduce IAP infestations in the fynbos of the GRNP has been achieved, when considering that approximately a third of the area targets as per the planning products have been 'implemented', of which less than a quarter has been treated to standard. Although better planning and prioritisation are often recommended to improve the efficiency of IAP management practices, our case study suggests that sound planning by itself does not ensure efficiency. Accordingly, Van Wilgen et al. (2011) proposed 'that the available management activities and practices be appropriately combined for each management category and strategically implemented collaboratively by affected parties at appropriate scales'. The general failure with reducing IAP infestations in our sample, which spanned a considerable period, significant and sustained investment (i.e. eight or more successive treatments), a diversity of projects, personnel, IAP species and environmental conditions, is disconcerting and suggests that these results are not unique (Fill et al. 2017; McConnachie et al. 2012).

Cover estimates and application of norms

IAP cover mostly appeared to be overestimated by WfW. A substantial proportion of the IAP cover records in WfW's information system greatly exceeded 100% (Figure 2), which is unlikely given that the IAP species that are commonly treated in the study area rarely form overlapping canopies or multiple strata. Compared to our field estimates, WfW substantially overestimated IAP cover over more than half the area that was assessed (Table 2; Figure 1). A large portion of WfW's records, furthermore, fell in high IAP cover classes (Figure 2), while another study (Van Wilgen et al. 2016) estimated that IAP cover in the fynbos of the GRNP was less than 25% over more than 85% of the area. Overestimation of IAP cover by WfW, thus, appears to be a perennial source of error with knock-on effects on various aspects of IAP management operations (discussed below).

Inaccurate IAP cover estimation is likely exacerbated by the lack of a clearly defined method for determining cover (or density), inconsistent application of any such method and observer subjectivity that may account for up to sevenfold variances in cover estimates for the same area (Loftus 2013; Neethling & Shuttleworth 2013). IAP cover estimates are mostly based on coarse infield visual assessments and 'gut feel', or worse, are often desktop-derived and are based on previous records of cover as per the WfW information system, or the deliberate allocation of incorrect (higher) cover values in order to disburse funds to meet expenditure targets, without concern as to whether the funds are used effectively (Loftus 2013; Neethling & Shuttleworth 2013). Accurate information on IAP cover is the basis upon which most aspects of IAP management rest. Without it, norms and workload-/cost-estimations become meaningless, while trends in IAP distributions and densities and the efficiency of management efforts cannot be measured (cf. Loftus 2013).

The observed relationship between workload/effort allocations and IAP cover estimates did not reflect a close correlation or stringent adherence to norms, with three- to fivefold deviations from the norms being common (Figure 4). Loftus (2013) likewise found large variation in the cost of IAP clearing per condensed hectare among five South African National parks, with the GRNP being the most expensive and most variable. The lack of adherence to norms was surprising in light of WfW operational staff often alleging that inappropriate norms are causing poor standard of work delivery. However, if norms are not rigorously applied (as is suggested by our results), and effort mostly gets allocated as requested (cf. Loftus 2013) regardless of IAP cover, then inappropriate norms cannot account for the poor standard of work observed. Moreover, if norms are not adhered to, and IAP cover records are unreliable, then the data on effort allocations (as captured in WfW's information system) cannot be used to evaluate effectiveness. In contrast, it is evident in the commercial forestry industry that the norms and standards relevant to weed treatments can be applied successfully and can contribute to effective operations (Rolando & Little 2009; Wagner et al. 2006).

The lack of a discrepancy observed in the effort – IAP cover relationship between two main IAP species groups (*Acacia vs. Pinus* or *Hakea*) (Figure 4) with disparate treatment requirements and distinct ecological responses, provides additional evidence that effort allocations do not match the nature of infestations and, thus, that norms are not adhered to. It, furthermore, suggests that cover, cost and effort estimations and allocations are often inaccurate and do not get adequately audited.

Recommendations to improve effectiveness

Interventions essential to improving the effectiveness of IAP management practices at project level largely relate to (1) improvement in IAP cover estimations, (2) additional quality control in terms of infield operations and (3) auditing of data captured in the WfW information system. In particular, we recommend the following:

- Increased alignment of project level annual plans and implementation with strategic planning.
- Implementation of effective protocol for IAP cover estimations that are relevant to specific biomes/regions and IAP species to be managed (cf. Loftus 2013; Neethling & Shuttleworth 2013).
- Compulsory infield assessments of IAP cover prior to contract generation and increased investment (in terms of travel, time, staff skills/training allowances) to this end. Outsourcing of this function should be considered as that may reduce subjectivity and scope for fraud, improve professionalism, specialisation and standardisation of this function, and yield data that are more comparable in space and time.
- Auditing of field data submitted for generation of contracts through the WfW information system, and in particular in terms of deviations from historical data in IAP cover.
- Ensuring that the WfW information system correctly applies the norms when calculating effort allocations in relation to IAP infestation attributes.
- Compulsory infield inspections of the quality of treatments applied during contract implementation, that is, mid-term and prior to contract payment.
- Allocation of funding by WfW to implementing agents specifically for monitoring and research, including compliance monitoring, ecological monitoring, and applied research applicable to the challenges faced by conservation agencies in the management of IAPs.

Many challenges experienced in the management of IAPs as revealed by this study relate to functions performed at WfW project management level. These include the development of annual plans that are aligned with the medium-term strategic plan, coordination of different processes involved in implementation, infield identification of IAP species and age classes, IAP cover estimations, application of norms in the generation and costing of contracts, choice of best treatment methods and infield inspections of the standard of treatment applications. In reality, the project management function in WfW is a daunting task, requiring a considerable and varied skillset and experience, including ecological, social and financial, with project managers typically managing annual budgets of ZAR 3–8 million. Due to poor remuneration, most applicants for project manager positions do not meet the tertiary education requirements, resulting in managers appointed being inadequately skilled. Furthermore, the mechanisms necessary to mentor and support these positions are not present within the implementing agents (cf. Coetzer & Louw 2012). A lack of career opportunities and succession planning also leads to a lack of sustainable management capacity, which in turn compromises the efficiency of project implementation.

We strongly advocate greater involvement of implementing agents (particularly in the case of conservation agencies) in all the major processes involved in IAP management, including planning, monitoring of IAP distributions, quality control of infield operations and training of all staff involved. The current approach that uses poverty-relief funds for alien plant control projects is politically attractive, and it has been the main reason that the control projects have received high levels of funding. However, as currently configured, the model imposes exacting requirements and demands that employment be maximised. These demands come at the cost of effectively achieving ecological goals that in the longer term would arguably support greater economic development (Van Wilgen & Wannenburgh 2016). In addition, the practice of issuing short-term contracts for clearing and follow-up (instituted as a developmental opportunity to disadvantaged contractors) requires cumbersome procedures to approve and implement and results in delays to work schedules and late payments to intended beneficiaries, substantially diluting the intended social benefits (Coetzer & Louw 2012; Hough & Prozesky 2012). It would be better to employ fewer, better-trained personnel on a more permanent basis. The current model also does not allow for capacity to be built within the conservation authorities who are ultimately mandated to manage protected areas. Hence, a scenario in which this funding is phased out, or channelled elsewhere, would leave the conservation agencies without embedded capacity and experience to manage invasions. We would, therefore, recommend that the funding be made available directly to conservation agencies to reduce the problems outlined herein.

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Competing interests

The authors declare that they have no financial or personal relationship(s) that may have inappropriately influenced them in writing this article.

Authors' contributions

T.K. was the project leader. T.K., J.A.B. and D.R.R. undertook field data collection. T.K., J.A.B. and N.S.C. were responsible for data processing and analyses. All authors, including B.W.v.W., made conceptual contributions.

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Appendix 1

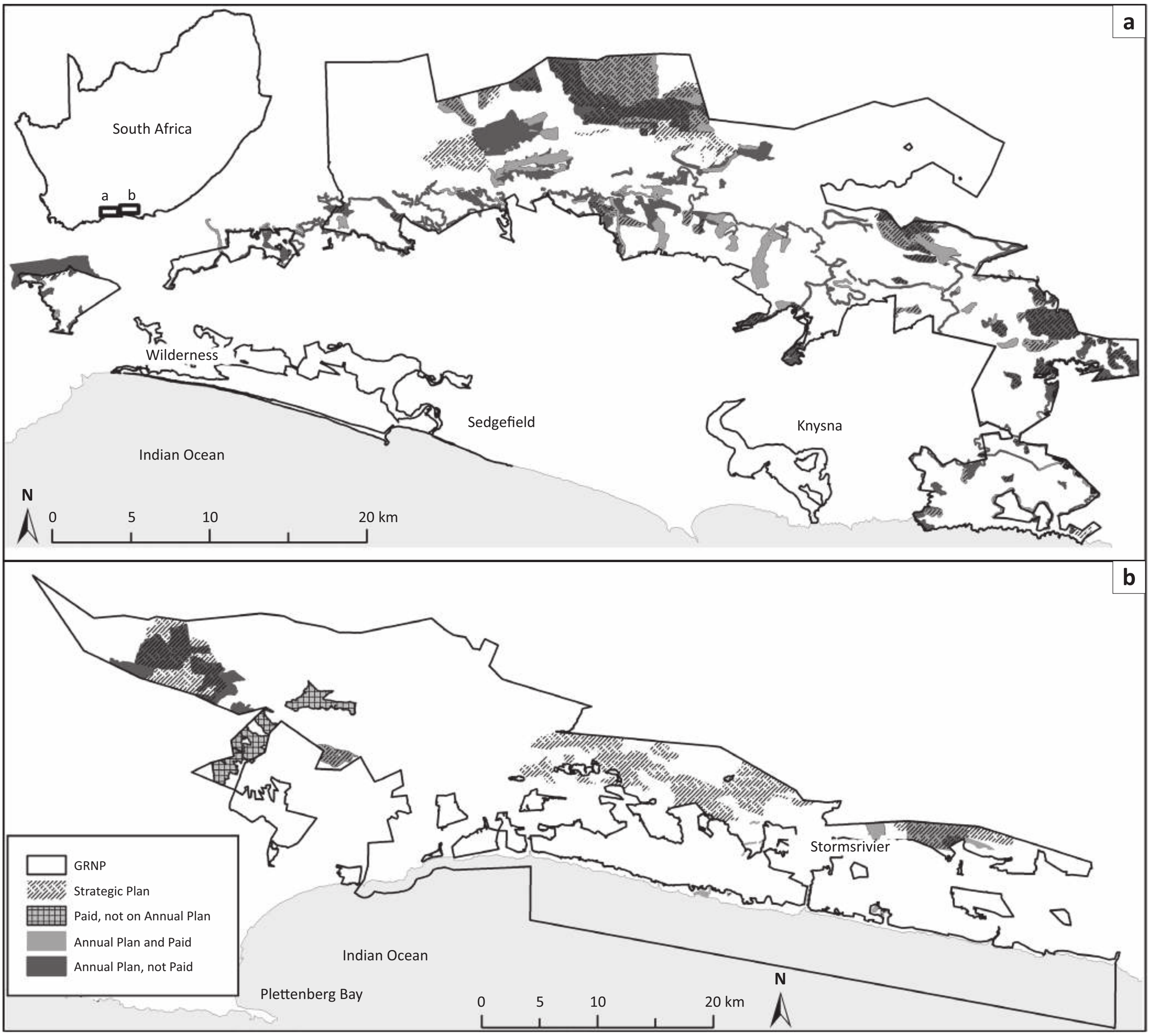

FIGURE1-A1: Geographic correlation between strategic medium-term plan ('Strategic Plan'), annual plan of operation ('Annual Plan'), and work recorded in Working for Water information system as contracted and paid ('Paid') during the 2014/2015 financial year in the Garden Route National Park ('GRNP').