On the implementation effectiveness and efficiency of ecological interventions in operational contexts: the case of Working for Water

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By

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ABSTRACT

There is little understanding of the implementation efficiency and effectiveness of restoring plant invaded landscapes within operational contexts. South Africa's Working for Water (WfW) programme is arguably the most ambitious alien plant control programme in the world, yet little is known about its cost-effectiveness and the challenges it faces in linking poverty and environmental objectives. My first aim was to assess the cost-effectiveness of invasive plant removal, and the factors that underpin its effectiveness over large spatial and temporal scales. The second aim was to compare the accuracy of evidence-based findings with managers' experience-based beliefs, and to assess whether managers are willing to change their beliefs after being exposed to it. The third aim was to assess the costs and benefits of removal versus removal followed by active native re-vegetation. My final aim is to assess the challenges and lessons learnt by managers linking ecological restoration with poverty alleviation objectives, specifically within the public works model. My study area was focused primarily on two WfW river catchment projects in the western region of the Eastern Cape province. I adopted an interdisciplinary approach drawing from a range of methods such as observational studies, statistical modelling and interviews with managers. The key findings were that control efforts in the two catchment projects are largely inadequate owing to many sites being re-invaded and not enough resources being allocated to the catchments. It would take between 54 and 695 years to clear the respective catchments. In terms of cost-effectiveness, my results exceeded previous estimates by 1.5 to 8.6 times for each catchment project. After being exposed to the evidence-based findings, the managers did not change their beliefs when it came to forecasting the future effectiveness. I found that active native re-vegetation after removal of invasive plants is very costly and that priority should be given to understanding the effectiveness of the removal treatments on native species recovery. The managers cited significant challenges in effectively and efficiently meeting the programmes dual objectives. Based on a broader review of the public works literature I recommend WfW re-examine the type of public works they currently use.

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ACRONYMS AND GLOSSARY

AIC – Akaike Information Criteria

BRT – Boosted regression trees

Cost-effectiveness – The cost of an outcome (effect) from a treatment

GIS – Geographical Information Systems

ECRP – Eastern Cape Restoration Programme

Efficiency – A treatment is efficient if it produces the maximum possible amount of output with a given set of inputs

Effectiveness – A treatment is effective if it makes a positive difference on the outcome variable regardless of cost

EPWP – Expanded Public Works Programme

Intervention ecology – The study of ecological interventions in a changing world. It provides a framework for integrating sub-fields such as conservation biology and restoration ecology

MAP – Mean annual precipitation

NPV – Net present value

PV – Present value

Sanparks – South African National Parks

WIMS – Water Information Management System

WfW – Working for Water

ZAR – South African Rands

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CHAPTER 1: INTRODUCTION

This thesis aims to contribute toward the following research gaps in the study of ecological interventions (Hobbs et al. 2011), with specific focus on the restoration of alien plant invaded landscapes. The first aim was to assess the cost-effectiveness of invasive plant removal, and the factors that might affect its cost-effectiveness over larger spatial and temporal scales relevant to operational contexts. The second aim was to compare the accuracy of evidence-based findings with managers' experience-based beliefs, and to assess whether managers are willing to change their beliefs after being exposed to evidence-based findings. The third aim was to assess the costs and benefits of removal versus removal followed by active native re-vegetation. The final aim was to assess the challenges and lessons learnt by managers linking ecological restoration with poverty alleviation objectives, specifically within a public works model. The overarching goal of my thesis is to contribute toward the understanding of how to improve the implementation efficiency and effectiveness of ecological interventions within real-world operational contexts.

RESEARCH CONTEXT

Since the start of this century significant advancements have been made on how managers implementing ecological interventions ought to develop strategies and evaluate their effectiveness. Firstly, the use of decision theory from economics has provided a rational optimisation approach to planning and strategy development (McCarthy et al. 2010). Secondly, the evidence-based concept, from the health sciences, has provided a framework for improving the quality of information used by managers when making decisions (Pullin and Knight 2005) and evaluating their interventions with counter-factual evidence (Ferraro and Pattanyak 2006). Despite these advancements there is a gap between what is proposed by the research community and its adoption by managers and their organizations (Stinchcombe et al. 2002; Knight 2007; Knight et al. 2008).

A significant knowledge gap is how managers and their organizations actually implement ecological interventions and to what affect, specifically in operational contexts (Brockington and Scholfield 2010; Sutherland et al. 2009). This bottom-up research approach could help to bridge the divide between research and management by understanding what the barriers are to implementing research innovations and assisting managers in adopting these innovations (Hall and Fleishman 2010). It could also improve scientific knowledge by learning from how organizations adapt their organizational design to specific contexts. For the above reasons I adopted a bottom-up approach to my research.

My research was undertaken whilst being an intern of the Eastern Cape Restoration Programme (ECRP), a WfW forum for managers and scientists to respond adaptively to project management issues. My experience draws from practical experiences working with teams restoring plant invaded areas, assisting project level managers with estimating costs of treatments and designing incentives for teams, to working in Working for Water's national head office assisting national managers with planning. I think this experience helped to improve the practical relevance of my research. In the remainder of this chapter I unpack the research gaps that my thesis aims to fill and give a brief description these gaps.

Gap 1: *The cost-effectiveness of invasive plant removal and the factors that influence its cost-effectiveness over spatial and temporal scales relevant to operational contexts*

Invasive alien plants pose a significant threat to the biodiversity and functioning of the world's ecosystems (Mack et al. 2000; Pimentel et al. 2005). Consequently, a sizable fraction of conservation budgets are often spent preventing and mitigating the impacts of invasions. The most cost-effective control method is prevention, followed by early detection and eradication (Hulme 2006). When the invasive population is established, biological control can be highly effective for some species and situations (van Driesche et al. 2010; de Lange and van Wilgen 2010); however, in most cases, costly ecological restoration treatment methods are required (Pyšek and Richardson 2011).

The most common restoration approach is to remove the invasive plants using mechanical and chemical treatments and thus to rely on the spontaneous recovery of native vegetation. In some cases active re-vegetation is also used (Kettenring and Adams 2011).

Given that limited funds are available for alien plant control – and the high opportunity costs of not spending the money on the above mentioned preventative measures – it is vital that where ecological restoration is undertaken, it is done so as cost-effectively as possible. For this to happen, decision makers need to know not only how effective their actions are, but also how costly they are (Naidoo et al. 2006). Without doing so resources cannot be allocated optimally to maximize scarce conservation funds (Murdoch et al. 2007; McCarthy et al. 2010). It also makes it difficult to learn from successes and failures, and to adapt accordingly to achieve desired outcomes (Sutherland et al. 2004; Grantham et al. 2011). Despite this, there is little evidence regarding the cost-effectiveness of restoring plant invaded areas.

In a recent systematic review and meta-analysis of invasive plant control research since the 1960s, Kettenring and Adams (2011) found that 71% of studies did not consider costs. They also highlighted how most studies were undertaken at such a small spatial and temporal scale that the results were not relevant to operational contexts – that occur at landscape scales. For example, in terms of temporal scale they found that only 7% of studies applied control treatments for greater than five years and 6% monitored treatment sites for greater than five years. In terms of spatial scale they found that only 20% of studies had a treatment plot size of greater than $1m^2$ and on only 9% of studies had treatment plots that were larger than 1 000 m^2. Finally, in terms of spatial extent they found most studies were undertaken over small areas.

Kettenring and Adams (2011) found that most of the experimental interventions they reviewed were implemented by academics. This finding was shared by Aronson et al. (2010a) who assessed the broader ecological restoration literature. This could arguably explain the small temporal and spatial scale of the experiments. Academics usually have limited time – needing to match a grant cycle – and budgets to implement interventions. Additionally, a lot of their time and effort is spent ensuring the validity of the findings from their interventions, for example, randomly selecting sites to avoid selection bias and the establishment of controls to be able to make counterfactual inferences. On the other hand, interventions implemented in operational contexts might occur over larger spatial and temporal scales but very few of these interventions are monitored and measured let alone use experimental criteria.

Working for Water (WfW) is arguably the world's largest and most ambitious alien plant control programme (Keonig 2009). Large numbers of alien plant species, including many trees and shrubs (Henderson 2001), have invaded South African ecosystems (Henderson 2007; Kotze et al. 2010). Some invasive trees, particularly those growing in riparian areas in its treeless biomes, reduce South Africa's scarce water supply relative to the lower biomass of the native vegetation (Görgens and van Wilgen 2004). This was one of the main arguments behind the initiation of the programme in 1995, and hence its name. However, unlike other national control programmes that focus on prevention and early detection, WfW spends the bulk of its budget on labour-intensive invasive plant clearing (Figure 1.1). This is partly because the programme is a public works project with the goal of creating employment in South Africa's impoverished rural areas (van Wilgen et al. 1998; Koenig 2009). Figure 1.2 describes WfW organizational structure, the key responsibility of its staff and the scale at which they make decisions.

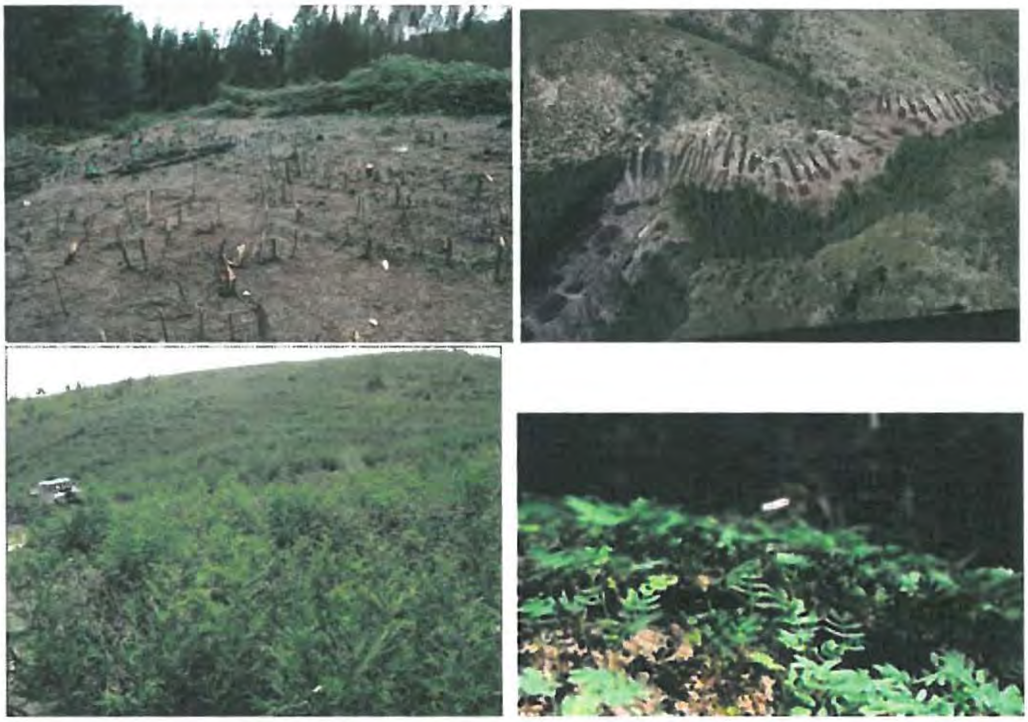
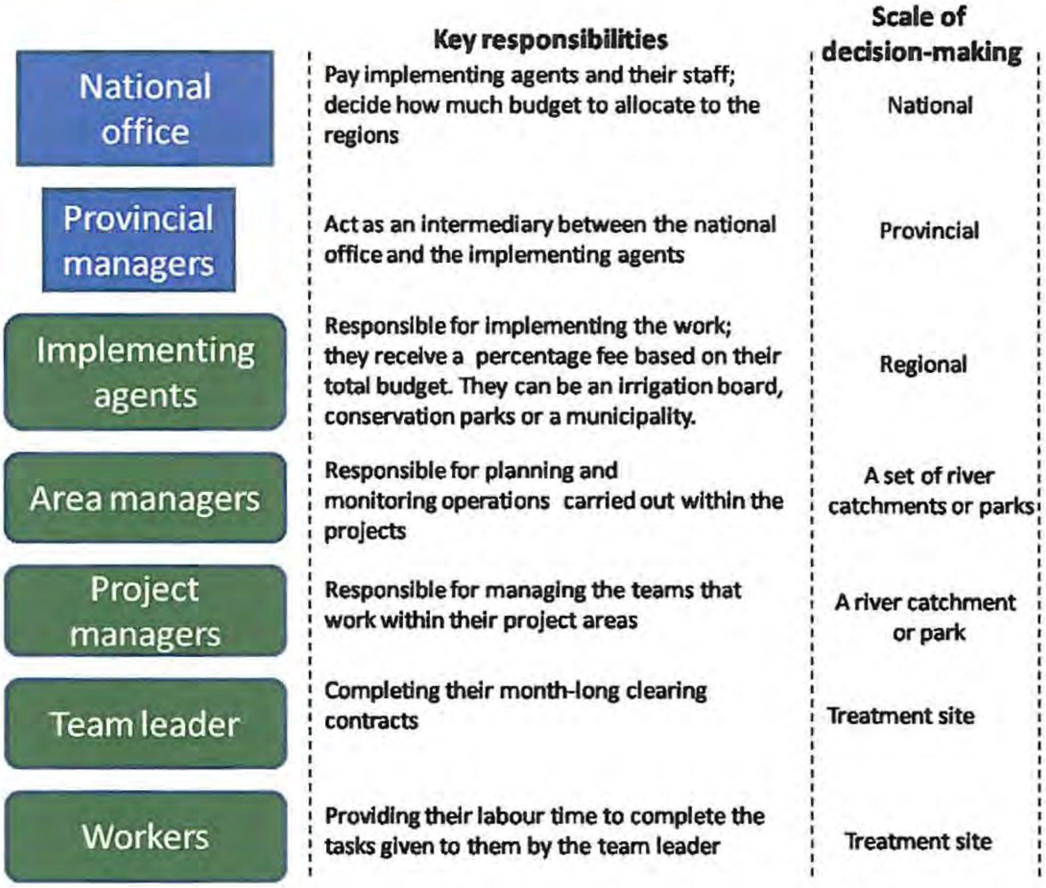


Figure 1.1 The top photos show sites where an invasive plant, *Acacia mearnsii,* is being felled at sites in the Kouga river catchment in the Eastern Cape, South Africa. The long-term success of control depends largely on how effectively invasive plant re-growth is eradicated. The bottom left and right photos show respectively *A. mearnsii* coppiced re-growth from felled stems and seed bank re-growth. Both types of re-growth need to be treated with herbicide spray applications before re-growth exceeds chest height, failing which the sites would have to be re-felled, at a far greater cost than the initial clearing.



	Key responsibilities	Scale of decision-making
National office	Pay implementing agents and their staff; decide how much budget to allocate to the regions	National
Provincial managers	Act as an intermediary between the national office and the implementing agents	Provincial
Implementing agents	Responsible for implementing the work; they receive a percentage fee based on their total budget. They can be an irrigation board, conservation parks or a municipality.	Regional
Area managers	Responsible for planning and monitoring operations carried out within the projects	A set of river catchments or parks
Project managers	Responsible for managing the teams that work within their project areas	A river catchment or park
Team leader	Completing their month-long clearing contracts	Treatment site
Workers	Providing their labour time to complete the tasks given to them by the team leader	Treatment site

Figure 1.2 Working for Water's organizational structure, key responsibilities of its staff and the scale at which they make decisions.

Since its inception in 1995, WfW has spent approximately 3.2 billion South African rands (ZAR) (1 US$ = approximately 7.4). Despite the substantial expenditure, it does not monitor the post-treatment alien plant cover at cleared sites. Instead it only measures alien plant cover prior to a treatment (Levendal et al. 2008; van Wilgen et al. 2012). This is compounded by the fact that it has not established clearly defined time-based goals that it can work towards and assess progress in achievement of the goals (van Wilgen et al. 2012).

In a recent national assessment of WfW, van Wilgen et al. (2012) found that the extent of invaded areas in South Africa has not decreased since the inception of WfW. Using records of WfW treatment areas, they showed that only a small fraction of the total invaded area was treated. They concluded that WfW should modify its strategy by focussing control efforts in high priority areas (van Wilgen et al. 2008). However, the study did not discuss WfW's cost-effectiveness in reducing alien plant cover on treatment sites, nor examine the factors that underpin its effectiveness.

Therefore my first objective was to assess WfW's cost-effectiveness in reducing invasive plant cover, and to determine what the predictors are of WfW's cost-effectiveness, specifically in terms of the cost per reduction in alien plant cover.

Gap 2: *The accuracy of evidence-based findings versus managers' experience-based beliefs, and if managers are willing to change their beliefs after being exposed to evidence-based findings*

There has been increasing emphasis placed on managers making decisions informed by evidence-based findings. The evidence-based concept was first developed in the medical field in the 1970s, and has only recently caught-on in conservation (Pullin and Knight 2004, 2005) and restoration (Ntshotsho et al. 2008). The basic concept is that before making a decision, managers would draw from all relevant available evidence which is rated according to its empirical quality (Table 1).

Table 1.1 Pullin and Knight's (2003) hierarchy of quality of conservation evidence based on the type of research undertaken. The hierarchy is a modification of one developed for the medical sciences.

Category	Quality of evidence
I:	Strong evidence obtained from at least one properly designed; randomized controlled trial of appropriate size.
II-1:	Evidence from well-designed controlled trials without randomization.
II-2:	Evidence from a comparison of differences between sites with and without (controls) a desired species or community.
II-3:	Evidence obtained from multiple time series or from dramatic results in uncontrolled experiments.
III:	Opinions of respected authorities based on qualitative field evidence, descriptive studies or reports of expert committees.
IV:	Evidence inadequate owing to problems of methodology e.g., sample size, length or comprehensiveness of monitoring or, conflicts of evidence.

In the absence of evidence-based knowledge, as in the case of Working for Water managers, their main source of information derives from their experience and personal observations. Work pioneered by Tversky and Kahneman (1974) has shown how people, including managers, are prone to a range of cognitive biases when making judgements and decisions. These biases, particularly overconfidence, can result in managers overestimating what they are capable of achieving and underestimating their likelihood of failure (Lovallo and Kahneman 2003). This is one of the central motivations of evidence-based knowledge, i.e. to rid conservation of anecdote and myth (Sutherland et al. 2004).

However, anecdote and myth have their advantages. In comparison to evidence-based knowledge, expert knowledge is less costly (Grantham et al. 2009) and can allow for rapid decision making. Gigerenzer and Brighton (2009) argue that to make accurate decisions, all available information need not be available. Furthermore, as mentioned, if the evidence-based knowledge does not match the spatial or temporal scale of decision making it can be misleading or inappropriate. In addition, in contrast to medicine, conservation and restoration managers usually have to manage hundreds of species, not one, and with significantly smaller research budgets. It is therefore far more difficult to create a comprehensive evidence-base of ecological interventions.

As Martin et al. (2012) argue expert based knowledge need not be restricted to scientists. Within a conservation planning context, Cowling et al. (2003) demonstrated the strengths and weaknesses of scientific information versus experience-based decision making, and suggested cross-checking them with each to improve the accuracy of decision making. Few studies have compared the accuracy of experience versus evidence-based knowledge. Owing to the paucity of evidence-based knowledge and its cost, the most should be made of managers' knowledge. Furthermore, a critical constraint that has been given almost no attention is whether conservation managers are actually willing to change their beliefs after being exposed to evidence-based findings. It is important to understand if and when evidence actually changes managers' beliefs, and how their biases, if any, influence their belief change.

Therefore, my second objective was to determine how the prior beliefs of the WfW managers differed from the evidence-based findings and if they were willing to change their beliefs after being exposed to these. I also sought to determine financial costs of acquiring evidence-based findings.

Gap 3: *Actual versus estimated costs and benefits of native re-vegetation after removal of invasive plants versus other restoration scenarios such as removal and containment*

A key finding of Kettenring and Adam's (2011) meta-analysis was that native plant recovery was poor after the removal of invasive plants. They argued that owing to the fact that only 30% of studies tested active native re-vegetation, future studies should test the effectiveness of native plant re-vegetation. On the other hand – in response the challenges of restoring plant invaded areas – Ewel and Putz (2004) argued that no action might be the best option in some circumstances. They argued that in many cases removal only aggravated recovery by damaging native species and opening gaps for secondary invasions. In the same vein Zavaleta et al. (2001) argued that invasive plant removal needed to be placed in the context of a whole ecosystem and not focused on a single species (Zavaleta et al. 2001). Davis et al. (2011) made the important point that whatever decision is taken, it needs to consider the costs and benefits of restoring plant invaded areas and not just its biophysical feasibility.

In South Africa, particularly in densely invaded riparian areas, there has been debate whether removal of the invasive plants alone will be sufficient for ecological restoration or if active native re-vegetation is also required (Holmes et al. 2008) (Figure 1.3). Riparian areas are especially prone to invasion because of the frequent disturbance events such as flooding, fire and grazing pressures (Richardson et al. 2007). Water use by invasive plants is also significantly greater than landscape invasions because of the higher water availability (Le Maitre 2002). Invasive plant control in these areas is therefore a high priority in semi-arid countries like South Africa.

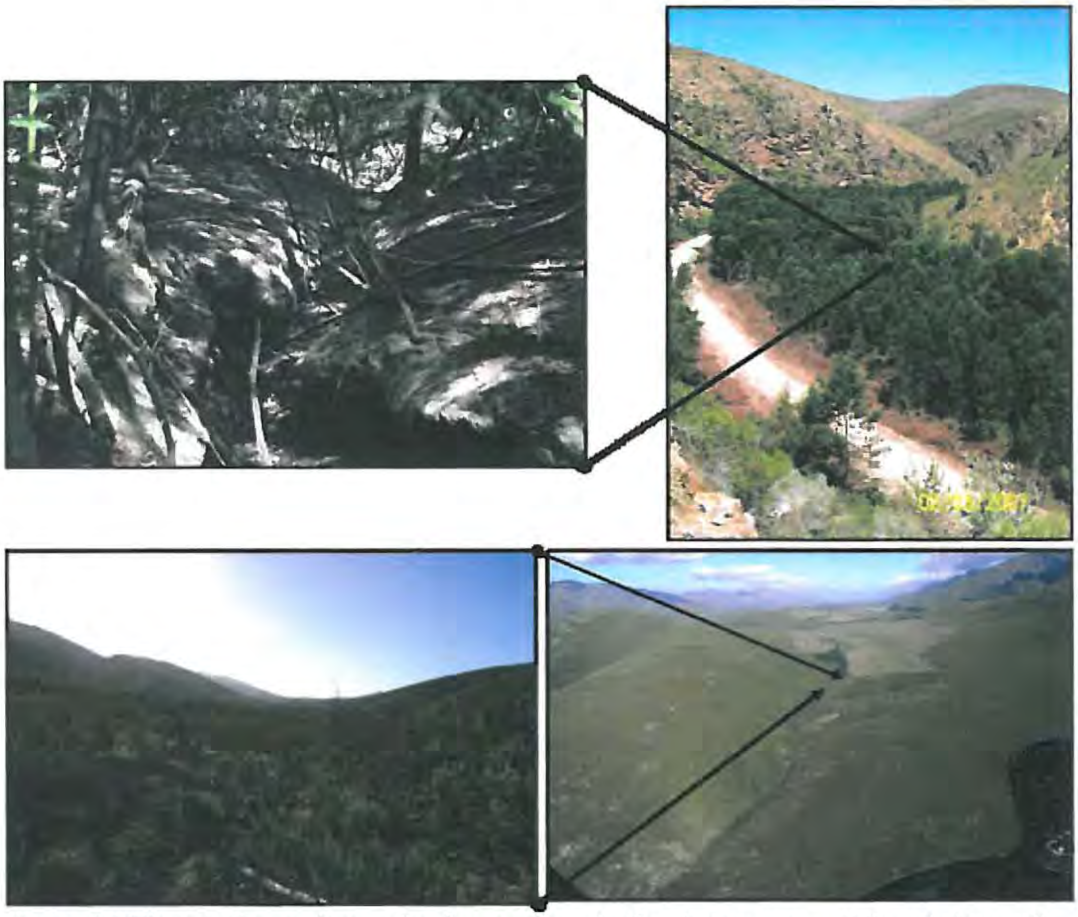


Figure 1.3 The top photos show a riparian area invaded by *Acacia mearnsii* from below and above the canopy in the Kouga catchments in the Eastern Cape. The bottom two photos show a riparian site that is on a trajectory toward recovery after invasive plants have been removed. Notice the lower biomass of the native fynbos vegetation in comparison the invasive trees. The higher biomass results in invasive trees using more water than the native vegetation especially in the Grassland and Fynbos biomes (Le Maitre et al. 2002). This was one of the primary arguments behind starting the Working for Water programme in 1995.

Despite active native re-vegetation being proposed as a solution to poor native plant recovery, few studies have measured the economic costs and benefits of it to determine its efficiency and feasibility in operational contexts (Kettenring and Adams 2011). As mentioned, a further issue is that most of the estimates are based on small temporal and spatial scales conducted by academics. The cost estimates are therefore predictions of costs in operational contexts and not actual cost measurements from operational contexts. As demonstrated in other disciplines, such as large scale engineering projects, ideally both estimates should be shown as the difference between projected and actual costs can be large (Flyvbjerg 2008).

Therefore, my third objective was to assess the costs and benefits of restoration scenarios involving containment, removal and active re-vegetation for riparian areas. For each scenario I calculated measured and estimated costs.

Gap 4: *The challenges and lessons learnt by managers in linking ecological restoration with poverty alleviation objectives within a public works organization*

Sometime ago Higgs (1997) called for an expanded view of ecological restoration that accounted for the socio-economic context within which restoration operates (Figure 1.4). This is because the success of ecological restoration is underpinned, not just by how effectively and efficiently it operates, but also because society supports it. Over a decade later, Aronson et al. (2010a) confirmed that few ecological restoration studies had responded to Higgs's (1997) call for an expanded view.

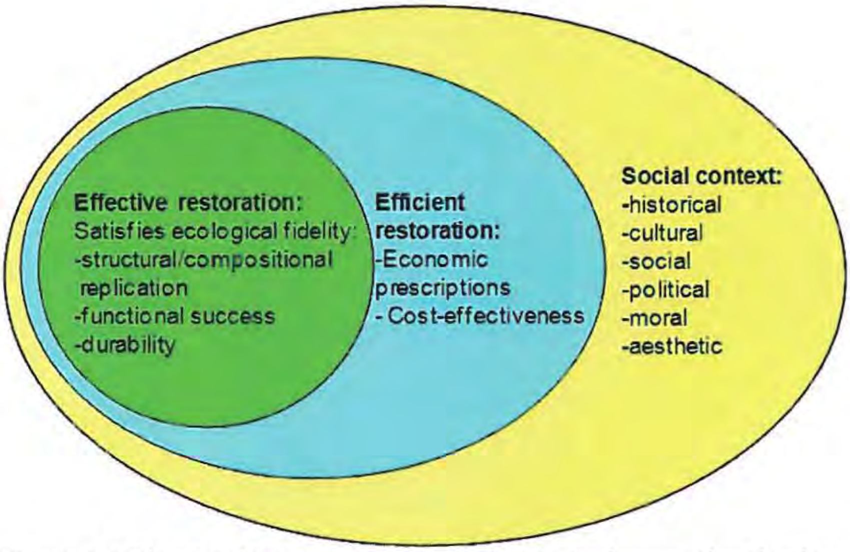


Figure 1.4 Higgs' (1997) expanded view of ecological restoration that incorporates the efficiency and social aspects of restoration.

In the ecological restoration literature, South Africa's WfW public works model has been heralded as a possible win-win strategy for alleviating poverty whilst simultaneously restoring ecological infrastructure (Woodworth 2006; Koenig 2009). Public works are government job-creation programmes that use labour to build or restore public infrastructure, for example, roads, hospitals, and in some cases, ecological infrastructure such as degraded land (Subbarao et al. 1997; Ninno et al.

2009). In addressing South Africa's social context – the need for economic development of the poor – WfW has managed to garner broader societal acceptance and political support in South Africa.

Figure 1.5 The photo on the right shows a township area in the Kouga river catchment of the Eastern Cape. Jobs are scarce in the area. The work that is available consists mostly of seasonal-dependent fruit-picking from the neighbouring farms. Despite significant economic growth since the collapse of apartheid, unemployment levels in South Africa have risen (Kingdon and Knight 2004). The only source of state aid for the working age unemployed is the possibility of getting temporary work in the Expanded Public Works Programme of which Working for Water forms a part.

Despite the attention given to it, as mentioned above, little is known about the challenges and set-backs faced by the WfW programme in meeting its dual-objectives. This is problematic because identifying challenges and set-backs is vital for learning adaption (Hobbs 2009). The few studies that have discussed the challenges and set-backs of the WfW programme have either focused exclusively on the poverty alleviation (Buch and Dixon 2004; Hope 2006) or environmental outcomes (Le Maitre 2002, van Wilgen et al. 2008), depending on the disciplinary persuasion of the researchers. There is therefore a need to understand the challenges faced by managers in effectively and efficiently providing its dual-objectives.

In addition to the above is important to understand how an organization's structure and design (i.e. government versus market based) shapes the effectiveness of its interventions (Sutherland et al. 2009). A lot of research on ecological interventions has examined how to design and implement interventions but little research has focused on this aspect. In the case of studies examining WfW, no studies have linked their findings to the broader public works literature and discussed how this organizational design might affect WfW's effectiveness.

Therefore, my fourth objective was to assess the challenges and lessons learnt by managers in linking ecological restoration with poverty alleviation objectives within a public works model.

CHAPTER OUTLINES

In this section I briefly describe the remaining chapter outlines. Chapters 2 to 5 are written as scientific papers.

In chapter 2, I evaluate the cost-effectiveness of reducing alien plant cover in two of WfW's catchment river clearing projects over a seven year period. I based this on a before-and-after evaluation by comparing a snapshot of post-treatment cover with pre-treatment cover across all 740 sites within the two catchment areas. I also used regression analysis to estimate the effect of predictor variables on the cost-effectiveness of invasive alien plant clearing.

In chapter 3, I used the opportunity provided by chapter 2 to ask three questions. Firstly, how do the initial beliefs of nine WfW managers, including all the managers responsible for the aforementioned projects, differ from the evidence-based findings in Chapter 2; and secondly, are managers willing to change their beliefs after being exposed to these findings. These two questions centred on the historical effectiveness of WfW in reducing invasive alien plant cover in the two catchment projects, as well as the managers' forecasts of WfW's future effectiveness, and the factors that underpin WfW's effectiveness. The third question focused on the financial costs of acquiring evidence-based knowledge. Specifically, I asked what proportion are these costs of the overall annual project budgets.

In chapter 4, I compare the costs and benefits of three restoration scenarios: namely removal, active restoration and containment. For each scenario, with the exception of containment, I included a high-efficiency and low-efficiency sub-scenario. I based the latter sub-scenario estimates on measurements of actual cost-effectiveness in the WfW programme and the former on estimates using work-study methods (Currie and Faraday 1977).The purpose of the scenario analysis was to compare the relative cost-effectiveness of the treatment scenarios as well as their financial feasibility. I therefore did not attempt to estimate the total economic value of the interventions. Instead, I focused on the most commonly measured financial ecosystem service benefits: water and livestock grazing (van Wilgen et al. 2008).

In chapter 5, I sought to understand what might have driven these challenges and constraints, and what I can learn from them, by interviewing WfW managers regarding the challenges they face in fulfilling the programme's goals.

In chapter 6, I conclude by summarizing the key findings and how successful I was in filling the gaps identified in this chapter. I also discuss the gaps that remain and what future research could address. In the final section I discuss policy suggestions for WfW by linking the findings of this thesis with agency theory and the organizational learning literature.

CHAPTER 2: EVALUATING THE COST-EFFECTIVENESS OF INVASIVE ALIEN PLANT CLEARING[1]

INTRODUCTION

Invasive alien plants pose a significant threat to the biodiversity and functioning of the world's ecosystems (Mack et al. 2000; Pimentel et al. 2005); consequently, billions of dollars have been spent preventing and mitigating the impacts of invasions (Pyšek and Richardson 2011). The most cost-effective approach is prevention, followed by early detection and eradication (Hulme 2006). When the invasive population is established, biological control can be highly effective for some species and contexts (van Driesche et al. 2010; de Lange and van Wilgen 2010); however, in most cases, costly mechanical clearing treatments are also required (Pyšek and Richardson 2011).

Few studies have measured the cost-effectiveness of clearing invasive alien plants over time (Kettenring and Adams 2011). Furthermore, most studies make measurements over small temporal and spatial scales making it difficult to extrapolate findings that are relevant to operational contexts (Kettenring and Adams 2011). Having no reliable measurement of cost-effectiveness hampers the optimal allocation of scarce conservation funds (Murdoch et al. 2007; McCarthy et al. 2010). It also makes it difficult to learn from successes and failures, and to adapt accordingly to achieve desired outcomes (Sutherland et al. 2004; Grantham et al. 2011).

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[1] This chapter has been accepted for publication, see McConnachie et al. 2012. The relative contributions of the authors were as follows. MMM collected and analyzed the data and also wrote the paper with the exception of the last section of the discussion. RMC helped formulate the study and write the paper. BVW helped structure the paper and wrote the section on "prognosis for cost-effective control" in the discussion. DM helped with the collection and processing of data used in the paper.

Large numbers of alien plant species, including many trees and shrubs (Henderson 2001), have invaded South African ecosystems (Henderson 2007; Kotze et al. 2010). Some of these plants reduce scarce water supplies and negatively affect biodiversity and the functioning of riparian zones (Le Maitre et al. 2000; van Wilgen et al. 2008). Growing awareness of the problem resulted in the formation of the government-funded invasive alien plant control programme 'Working for Water' (WfW) in 1995. It is arguably the largest conservation project in Africa (van Wilgen 2009) and the world's most ambitious invasive alien plant control programme (Koenig 2009). Unlike other national control programmes that focus on prevention and early detection, WfW spends most of its funds on labour-intensive clearing because, as a public works project, it is expected to create employment in South Africa's impoverished rural areas (van Wilgen et al. 1998; Koenig 2009).

Despite its size, WfW appears to be falling short, at a national scale, of the expectation that it would have brought invasive alien plant problems under control within a reasonable timeframe (van Wilgen et al. 2012). Little is known about the cost-effectiveness of its clearing treatments at a project scale, because of a lack of clear, time-based goals, and a system of monitoring and evaluation to assess progress towards these goals (van Wilgen et al. 2012; Levendal et al. 2008). Currently, WfW only records plant cover, treatments and costs on specific sites where contracts are awarded for clearing work. Thus, there is no assessment of the effectiveness of the work done at a landscape scale because only the input variables (money spent, area cleared, and jobs created) are recorded. It is therefore not possible to assess effectiveness in terms of progress towards the goal of restoring plant invaded landscapes.

In a recent national assessment of WfW, van Wilgen et al. (2012) found that despite substantial spending on control operations (3.2 billion South African rands (ZAR), 1 US$ = approximately ZAR 7.4), the extent of invaded areas in South Africa had grown since the inception of WfW in 1995. Using records of WfW treatment areas, van Wilgen et al. (2012) showed that only a small fraction of the total invaded area was treated. They concluded that WfW should modify its strategy by focussing control efforts in high priority areas (Forsyth et al. 2012). However, the study did not address WfW's cost-effectiveness in reducing invasive alien plant cover at the scale of treatment sites, nor did it explain the factors that influence the cost-effectiveness of treatments.

In this paper, I evaluate the cost-effectiveness of reducing invasive alien plant cover in two of WfW's river catchment clearing projects over seven years. I based this on a before-and-after evaluation by comparing post-treatment cover with pre-treatment cover across all 740 sites within the two larger catchment areas. I also assessed the variables that had the greatest effect on the cost-effectiveness of invasive alien plant clearing.

METHODS

Study area and background to the projects

I conducted my study in the Krom (631km^2) and Kouga (2 426 km^2) river catchments in the Eastern Cape Province of South Africa (Figure 2.1), specifically, in those parts of each catchment where WfW had implemented projects to clear invasive alien plants. These two projects are among WfW's oldest (operating since 1995) and largest in terms of hectares cleared and jobs created.

WfW managers allocate contracts within each project that specifies a treatment site of alien-plant-invaded land that must be cleared within a month. Each treatment site is assigned to a team comprising a team leader (contractor) and 10-15 labourers, recruited from the large numbers of unemployed people in local towns. Each project has, on average, five to seven operational clearing teams at any time.

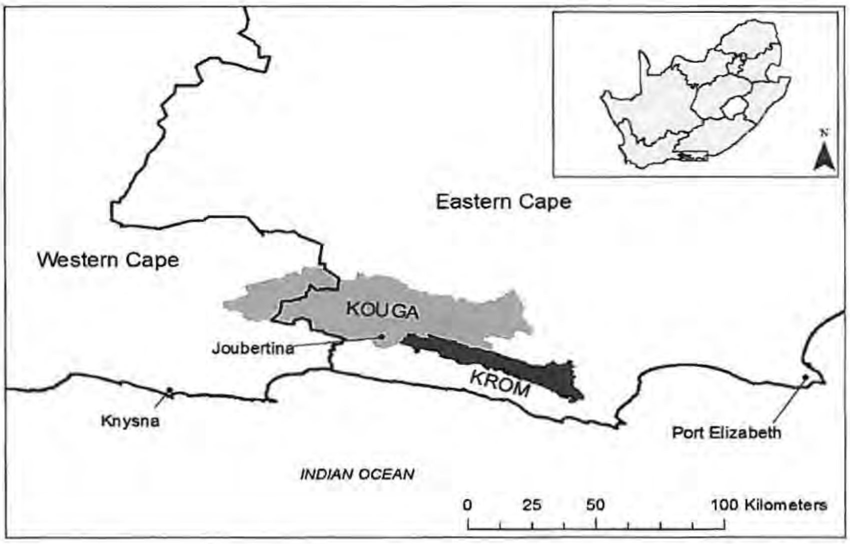

Figure 2.1 Location of the Kouga and Krom river catchments within the Eastern Cape Province, South Africa.

The principal invasive alien plant species in both catchments is the tree *Acacia mearnsii* (black wattle), native to eastern Australia. When mature, *A. mearnsii* is between 5 and 10 m tall. This species is the most prolific invader in South Africa in terms of its spread and impact on ecosystem services (de Wit et al. 2001), and as a result WfW have spent the most money on this species (van Wilgen et al. 2012). Of less importance in the study area are other Australian *Acacia* species, along with species of *Pinus, Eucalyptus* and *Hakea.*

The effective control of coppicing species like *A. mearnsii* requires felling, followed immediately by the careful application of herbicide to the cut stems. This kills the plant and thus prevents coppicing. Clearing also stimulates the germination *en masse* of seeds from a large and persistent soil-stored seed bank (Holmes et al. 2008). Numerous and timely follow-up treatments are required to treat both seedlings and coppice re-growth by spraying with herbicide, and is compounded when previous treatments were poorly executed. Re-growth taller than 1.8 m is unaffected by herbicide and plants must be re-felled, which is far more costly (Holmes et al. 2008). During the evaluation period, WfW's policy regarding clearing on private land was that the landowners would agree to maintain cleared sites after WfW's second follow-up treatment.

Both catchments support predominantly fynbos vegetation associated with nutrient-poor, sandy soils that prevail in the area. Fynbos is a fire-prone shrubland (Cowling 1992) that is vulnerable to invasion by alien trees, even in the absence of anthropogenic disturbance (Richardson and Cowling 1992). Rainfall is evenly distributed throughout the year in both catchments. The Krom catchment has a higher mean annual rainfall (690 mm) than the Kouga catchment (472 mm) (Schulze 2008).

The catchments supply 50% of the water for Port Elizabeth, the largest city in the Eastern Cape and an important economic development node in the province. Water is increasingly limiting economic growth in South Africa (Blignaut and van Heerden 2009), and extensive invasions of alien plants exacerbate this problem (Görgens and van Wilgen 2004); hence, the implementation of WfW projects in these two catchments.

Evaluating the cost-effectiveness of invasive alien plant clearing

I measured the cost-effectiveness of invasive alien plant clearing at both a project (either the Kouga of Krom catchments) and site (individual clearing contracts within catchments) level. The site-level data were used exclusively for the regression analysis (see below). I measured cost-effectiveness by dividing the funds spent on a project or site by the change in invasive alien plant cover (pre-treatment invasive alien plant cover minus post-treatment cover). I converted the estimates of plant cover to 100% equivalent cover ("condensed ha") for comparison across sites, using the formula: $C = d/100 \times A$, where C is the area expressed as condensed ha, d is the % canopy cover, and A is the area in ha that was treated. My unit of analysis was therefore the cost (ZAR) per condensed ha reduced during the evaluation period.

I assessed the change in invasive alien plant cover by comparing post-treatment cover (December 2008) with the first recorded pre-treatment cover, across all of the 740 treated sites in the two projects (data capture commenced only in 2002, so first records were from 2002 or later). According to the project manager of each catchment, some sites were treated prior to 2002; however, there are no recorded data for these treatments and therefore no way of knowing which sites had been treated. I therefore used the first recorded pre-treatment cover of invasive alien plants as the baseline from which to assess cost-effectiveness. A site was deemed treated if it had been given at least one treatment. The total area treated in both projects was 11 202 ha. The average area of a site was 15.2 ha, ranging from 0.03 to 227.6 ha.

Pre-treatment invasive alien plant cover and costs

I identified treatment sites using WfW's spatially-explicit database, the Working Information Management System (WIMS). Contracts are awarded to clear each site, and WIMS records the spatial boundary of the site, its date of implementation, operational costs, pre-treatment type and aerial canopy cover of invasive alien plants. I included overhead costs (management and implementing agent fees) in the cost estimate, but excluded national WfW management costs as no reliable estimates were available. I inflated all costs to 2010-value ZAR using the consumer price index.

I included sites in the assessment that the two project managers were confident did not contain WIMS database error. I therefore excluded 103 of the 433 Kouga sites and 17 of the 427 Krom sites from further analysis. Finally, I also checked that the WIMS database had been correctly updated by comparing records with the original hardcopy list of treatments stored by the implementing agent. I added 26 and 63 treatments for the Kouga and Krom, respectively. Thus, I recorded in total 2 213 treatments (987 Kouga and 1 226 Kouga) on the 740 sites that were treated.

Invasive alien plant post-treatment cover

I estimated the post-treatment percentage canopy cover of invasive alien plants for the three dominant invasive alien plant species present on a site for all the sites using the same methods used to estimate the pre-treatment cover. The methods are based on guidelines related to the type of invasive alien plant, growth form and density (Working for Water Programme 2003). Because of the large areas involved and the difficulty of estimating cover on the ground, I took aerial photographs of all of the sites from a helicopter, and then made the cover estimates using these photographs. I photographed most (>90%) of the sites in December 2008, and the remainder in February and March 2009.

To ensure that the pre-treatment cover estimates were consistent with my post-treatment estimate, I asked a mapping consultant, who had performed some of the pre-treatment cover estimates in the projects, to give his post-treatment estimate for 28 of the sites I had assessed. He used the same photographs I used to make my estimates. In comparison to his estimates, I underestimated densely covered (50-75%) invasive alien plant sites and closed covered (>75%) sites and slightly overestimated medium (25-50% invaded) and scattered (5-25% invaded) covered sites. For each cover class described above, I adjusted my estimate based on these differences in interpretation.

Future effort required to complete clearing

I estimated the time and cost that would be required to remove remaining invasive alien plants from both the site and project areas. Because these plants are unlikely to be entirely eradicated from the area, I defined successful removal as a state where the control would only require low-cost maintenance treatments (Marais et al. 2004). I based my estimates on the respective rates of removal and cost-effectiveness achieved in each project during the treatment period (see above). For estimating the total cost that would be needed for complete removal, I multiplied my measurement of cost-effectiveness in reducing invasive alien plant cover in each project by the total number of condensed hectares remaining on both the sites and the projects. For the invaded area of the sites, I used my estimate of the remaining (post-treatment) condensed invasive alien plant hectares. For invaded area of the entire project, I used Kotze et al.'s (2010) estimate of condensed hectares of invasive alien plant cover in 2008. I estimated the time that would be needed to clear the remainder of the project areas, by dividing the estimate of remaining invaded area (in condensed ha) by the rate of removal (the average number of hectares successfully cleared per year between 2002 and 2008), assuming no spread. Lastly, I estimated the invasive alien plant spread rate that could be contained by the respective projects. This was calculated by dividing the rate of removal by the estimate of remaining invaded area (in condensed ha). In both the cost and time projections I assumed that future cost-effectiveness would be the same as the historical cost-effectiveness that I measured.

Factors affecting the cost-effectiveness of site treatments

Data sources

I used the estimated cost to eradicate one condensed hectare of invasive alien plant cover as the response variable in all the models described below. My analysis only included sites in which invasive alien plant cover had been reduced (pre-treatment – post-treatment cover > 0). This approach led to the exclusion of 217 of the 740 sites where cover had actually increased (36.7% and 20.7% of the Kouga and Krom sites respectively). I selected potential predictor variables based on discussions with nine WfW managers familiar with the project area. I selected variables indicative of biophysical, operational and landowner issues related to the cost-effectiveness of clearing (Table 2.1). I extracted the operational data from WIMS, and the landowner information from interviews with the managers of each project.

I only selected variables for the regression analysis that had sufficient variation to model its effect on the response variable. I therefore excluded variables related to landowner willingness to do follow-up treatments, tenure type (private versus public) as well as the treatment type used (clearing only versus clearing and native re-planting).

Table 2.1 Variables used in the single and multiple regression analyses. The response variable is "Cost per condensed ha reduced". Only sites where there was a reduction in alien plant cover (n=524) were modelled. WIMS = Water Information Management System; NA = categorical variables; ZAR = South African rands; 1 US$ = approximately 7.4 rands.

Variable	n	Min.	1st Qu.	Median	3rd Qu.	Max	Source
Altitude - average (m)	524	200.8	315.1	439.7	600.2	1081	Dept. Land Affairs
Area of all sites on landowner property (ha)	524	4.1	184	322.5	820.6	1194	WIMS
Area of site (ha)	524	0	2.1	7.7	15.8	227.6	WIMS
Cost per condensed ha reduced (ZAR)	524	509	5062	7897	15970	1008000	Assessed
Days since last treatment	524	29	293	790	1120	2249	WIMS
Distance to closest road (m)	524	0	0	2.3	122.3	2904	Dept. Land Affairs
Distance to project office (m)	524	2719	19610	28700	38850	58150	GIS analysis
Number of treatments	524	1	1.8	3	4	9	WIMS
Pre-treatment invasive plant cover (%)	524	0.6	9.6	33	60	100	WIMS
Pre-treatment invasive plant species	524	NA	NA	NA	NA	NA	WIMS
Project domain (Kouga or Krom)	524	NA	NA	NA	NA	NA	WIMS
Rainfall - annual average (mm)	524	420.3	550.5	670.9	722.1	838.2	Lynch (2004)
Money spent per hectare (ZAR)	524	34.3	785.6	1935	4214	21030	WIMS
Riparian area (%)	524	0	0	0.1	0.5	1	Dept. Land Affairs
Slope - average (degrees)	524	0	4.2	8.5	12.7	34.6	Dept. Land Affairs

I estimated the percentage riparian area of a site by buffering perennial and non-perennial rivers by 83 m and 41 m, respectively (Cullis et al. 2007). I used point estimates of mean annual precipitation (MAP) at a 0.01-degree resolution to estimate site rainfall, and converted these point data to raster data to derive an average MAP estimate for each site.

Regression models of cost-effectiveness

I estimated the individual effect of each predictor variable on the response variable (cost per condensed ha reduced) by using a separate linear regression model for each predictor variable. Both the response variable and each predictor variable were log transformed to improve the fit and ease of interpretation where appropriate (Gelman and Hill 2007).

I then used multiple linear regression to examine the combined effect of the predictor variables on cost per condensed ha reduced. I used a full stepwise selection analysis (both directions) using Akaike Information Criteria (AIC) to identify the best combination of predictor variables (Burnham and Anderson 2002). I ran all the above regressions in R 2.13.1 (R Development Core Team 2011).

RESULTS

Effectiveness, treatment costs and cost-effectiveness

The total condensed hectares of invasive alien plant cover across the sites declined from 2 013 to 1 055 between 2002 and 2008. Most (86%) of this decline occurred in the Krom catchment (Figure 2.2). In the Kouga catchment, mean alien plant cover declined only from 888 to 755 condensed hectares, and on 36.2% of the treated sites, invasive alien plant cover actually increased despite the clearing effort.

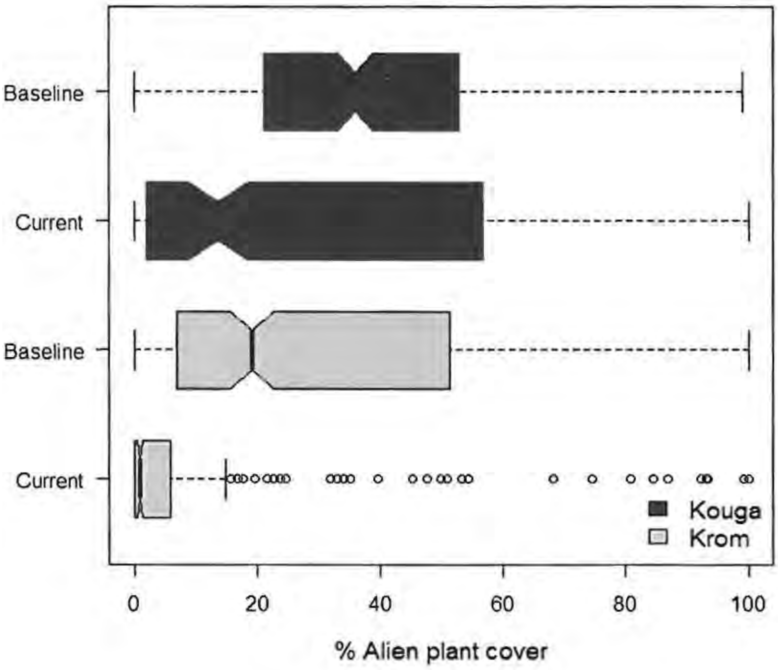

Figure 2.2 Boxplots showing the distribution of invasive alien plant cover for pre-treatment (baseline) and post-treatment (current) levels on 740 sites treated in the Krom and Kouga catchments in the Eastern Cape Province, South Africa (where boxplot notches do not overlap, medians are significantly different P < 0.05).

Only 1.4% of the Kouga's catchment area and 5% of the Krom's area were treated, and 97% of these treatments took place on private land. According to the two project managers, none of the landowners contributed to WfW's cost of clearing. In addition, 29% of the landowners followed up on WfW's efforts only occasionally and 61% not at all, despite agreements to do so.

The bulk of the pre-treatment invasive alien plant cover was made up of *Acacia* spp. (principally *Acacia mearnsii*) (65.0%) followed by *Eucalyptus* spp. (15.8%) and *Pinus* spp. (13.4%). The post-treatment cover was still dominated by *Acacia* spp. (62.5%), whilst *Pinus* spp. had increased (18.6%) and *Eucalyptus* spp. (3.0%) had declined.

The average amount of money spent on a site was ZAR 2 634 (sd. ±2 449) per ha (ranging from ZAR 10 to ZAR 21 031, expressed as 2010-value of ZAR). Overall for both projects, it cost ZAR 20 113 per condensed ha reduced (dividing the total cost by the total reduction in invasive alien plant cover). The Kouga project was far less cost-effective, costing ZAR 70 517 per ha compared to ZAR 11 987 for the Krom catchment. The number of treatments per site ranged from one to nine treatments, averaging approximately three per site.

WfW spent ZAR 19.27 million on the two projects during the assessment period (2002-2008) (Table 2.2). Most of this cost was made up of operational costs and training for the contractors and their teams (78.3%). The rest was spent on management and implementing agent fees. Labour (workers and contractors) costs represented 30% of the total costs and 40% of the operational costs. Of the money spent on labour, 20% went to the contractor with the rest spent on the team. The remainder of the operational costs was spent on transport, equipment and chemicals.

Table 2.2 Costs of the Kouga and Krom Working for Water projects between 2002 and 2008 (ZAR millions, ZAR = South African rands; 1 US$ = approximately 7.4 rands). National and provincial overhead costs not included.

	Kouga	Krom	Total (%)
Operational costs	7.35	7.75	15.10 (78.4)
Management costs	1.18	1.24	2.42 (9.1)
Implementing agent levy costs	0.85	0.9	1.75 (12.5)
Total cost	9.38	9.89	19.27 (100)

Future effort required to complete clearing

Assuming current costs and clearing rates, and no additional spread of invasive alien plants, it would take considerably longer, and cost substantially more, to effectively clear invasive alien plants to maintenance levels in the Kouga than the Krom catchment (Table 2.3). At the clearing rate of the Kouga project, the WfW programme would only be able to contain the invasions if they spread at a rate of 0.14% or less annually, compared to 1.84% in the Krom project. Both estimates are well below the realistic annual spread rate of 8.5% (Le Maitre et al. 2002). Thus, although the Krom catchment had a higher level of efficiency, both are inadequate to contain spread. Predictably, removal of invasive alien plants from the sites, compared to the entire catchments, would require substantially less time and money. Despite this, I estimate it will still take 40 years to reduce invasions by alien plants from the remainder of the Kouga's treated sites to levels where low-input maintenance would be required.

Table 2.3 Extrapolated time and costs to complete the removal of invasive alien plant-invaded areas at the catchment and site scales in the Kouga and Krom Working for Water projects. Also shown is the invasive alien plant spread rate that the respective projects could contain. The projections assumed current budgets, costs and clearing rates (ZAR = South African rands; 1 US$ = approximately 7.4 rands).

	Catchments		Sites	
	Kouga	Krom	Kouga	Krom
Cost per condensed ha reduced (ZAR)	70 517	11 987	70 517	11 987
Average annual WfW budget (millions ZAR) between 2002-2008	1.34	1.41	1.34	1.41
Average annual condensed ha reduced between 2002-2008	19	118	19	118
Remaining condensed ha in 2009	13 209	6 413	755	300
Years to complete removal (assume no spread) from 2009	695	54	40	3
Total cost (millions ZAR) of removal from 2009	931.47	76.87	53.27	3.59
Hypothetical invasive plant spread rate (%) that could be contained	0.14	1.84	2.52	39.34

The effect of variables on cost-effectiveness of site treatments

Single predictor regression variable relationships

Overall, the single predictor variable models explained a low amount of the variability in cost per condensed ha reduced (Table 2.4). Mean annual rainfall and the average altitude of a site had the largest effect, – positively and negatively influencing the cost per condensed ha reduced, respectively. Pre-treatment invasive alien plant cover, on its own, was not significant and its effect size was relatively small (-0.22% with a 68% confidence interval of ±0.08). Other variables that had strongly significant effects included money spent per ha, distance to project office, number of treatments and pre-treatment invasive alien plant cover.

Table 2.4 Single regression models showing the individual relationship between each predictor and the response variable (Cost per condensed ha reduced (ZAR)). Both the predictor and response variables are log transformed with the exception of the categorical predictor variables and the variable "Number of treatments". This transformation allows coefficients to be interpretable as approximate proportional differences for a change in the response variable i.e. a difference of x% in the predictor variable is associated with a difference of the same x% difference in the response variable (Cost per condensed ha reduced) multiplied by the coefficient estimate.

	Intercept	Coefficient estimate	Coefficient std. error	D.f.	Residual standard error	Adjusted R^2	p-value
Altitude - average (m)	6.20***	0.494***	0.115	522	1.003	0.032	<0.001
Area of all sites on landowner property (ha)	9.82***	-0.105*	0.043	522	1.015	0.001	0.015
Area of site (ha)	9.21***	-0.0001	0.026	522	1.021	-0.002	0.997
Days between treatments – average	10.62	-0.203	0.123	391	0.004	0.004	0.100
Days since last treatment	9.94***	-0.115*	0.052	522	1.016	0.008	0.026
Distance to closest road (m)	9.19***	0.014	0.014	522	1.019	0.000	0.303
Distance to project office (m)	6.64 ***	0.254***	0.068	522	1.007	0.024	<0.001
Money spent per hectare (ZAR)	7.27***	0.261***	0.038	522	0.978	0.080	<0.001
Number of treatments	8.53***	0.225***	0.022	522	0.934	0.161	<0.001
Pre-treatment invasive plant cover (%)	8.83	-0.271***	0.039	522	0.976	0.084	0.086
Pre-treatment invasive plant species	9.26	NA	NA	518	1.021	-0.004	0.683
Project domain (Krom or Kouga)	9.33***	-0.198*	0.091	522	1.016	0.007	0.029
Rainfall - annual average (mm)	14.49***	-0.818**	0.038	522	1.012	0.014	0.004
Riparian area (%)	9.25***	0.010	0.013	522	1.020	-0.001	0.419
Slope - average (degrees)	9.12***	0.056	0.031	522	1.017	0.005	0.065

*Pr(t) < 0.05; ** Pr(t)< 0.01; *** Pr(t)< 0.001

Multiple regression predictor variable relationships

The predictor variables retained in the AIC-selected model explained a greater amount of variance in cost per condensed ha reduced than the single regression models ($R^2 = 0.67$, d.f. = 516; AIC = 552.59) (Table 2.5). The variables that had the largest effect on cost-effectiveness were the pre-treatment percentage invasive alien plant cover, followed closely by the money spent per hectare and the average altitude of a site, a proxy for access. To put these estimates into context, holding other variables constant, a site with 25% pre-treatment invasive alien plant cover compared to a site with 50% invasive alien plant cover (i.e. 50% difference in cover) would cost 50.5% (with a 68% confidence interval of ±3.5) less per equivalent condensed ha reduced. Thus if the site with 50% invasive alien plant cover cost ZAR 20 000 per condensed ha reduced, the site with an invasive alien plant cover of 25% would cost ZAR 30 505 per condensed ha with a 68% confidence interval of ±735. Surprisingly with regard to the amount of money spent per ha, after accounting for pre-treatment invasive alien plant percentage cover and site access, a 50% increase in this predictor variable would result in a 49% (with a 68% confidence interval of ±3.6) increase in the cost to remove a condensed ha of invasive alien plant cover. Thus, the amount of money invested into a site did not equate to an improved return on investment.

Table 2.5 Variables retained, via AIC step selection, in the multiple regression model after first regressing "Cost per condensed ha reduced" on the 14 predictors listed in Table 2.1 (d.f. = 516, adjusted $R^2 = 0.67$, Residual std. error = 0.585, AIC =552.59, p-value < 0.0001). Both the predictor and response variables are log transformed with the exception of the categorical variables. This transformation allows coefficients to be interpreted as approximate proportional differences for a change in the response variable i.e. a difference of x% in the predictor variable is associated with a difference of the same x% difference in the response variable (Cost per condensed ha reduced) multiplied by the coefficient estimate.

	Estimate	Std. error	Pr(>|t|)
(Intercept)	-6.17	1.626	<0.001
Altitude – average (m)	0.49	0.077	<0.001
Money spent per hectare (ZAR)	0.98	0.036	<0.001
Pre-treatment invasive plant cover (%)	-1.01	0.035	<0.001
Area of site (ha)	0.03	0.017	0.084
Area of all sites on landowner property (ha)	-0.07	0.028	0.014
Distance to project office (m)	0.14	0.046	0.002
Rainfall - annual average (mm)	0.4	0.191	0.037

DISCUSSION

Comparison to existing estimates of cost-effectiveness

My measurements of WfW's cost-effectiveness were far lower than estimates made in other studies. For example, Marais and Wannenburgh (2008) estimated the average cost per hectare treated as ZAR 3 301 (*Acacia* spp.) for dense invasive cover (>75%). Converting this to a condensed hectare and 2010 ZAR it would equal approximately ZAR 4 463. Le Maitre et al. (2002) estimated the average cost per condensed hectare ranging from ZAR 2 053 to ZAR 8 211 (inflation adjusted from 2002 to 2010 ZAR) in an assessment of the economic feasibility of invasive clearing across four catchments. Therefore, my overall estimate was 2.4 times greater than the Le Maitre et al.'s (2002) highest estimate (8.6 times greater for the Kouga and 1.5 times greater for the Krom).

Although my estimates are the highest yet made, they are almost certainly an underestimate, which means that the situation is actually worse than my estimates might suggest. In particular, I excluded sites that WfW recorded as treated, but were in fact never treated. Furthermore, I was not able to include national and provincial costs, nor was I able to evaluate the sites treated prior to 2002 (many of which had been re-invaded according to the two project managers). Estimating the cover from aerial photographs also meant that I could not detect early re-growth via seedling or re-sprouts, leading to underestimates of cover. According to senior managers in the Eastern Cape, the Kouga and Krom are considered to be the most effective projects in the province. Therefore, the projects I evaluated are likely to be more cost-effective than the other WfW projects in the province. The reason that my measurements of cost-effectiveness were so much lower than other studies could be explained by the high post-treatment re-invasion at many of my sites, something that had not been realized in earlier estimates. My findings of the money spent on treatments were similar to other studies.

The ineffectiveness in reducing invasive alien plant cover has implications for the time and cost required to reduce the cover of invasive alien plants to maintenance levels. For example Marais et al. (2004) estimated, based on clearing rates at the time that it would take between one and 83 years to clear invasive plants from South Africa, depending on the species. This was based on the assumption that no further spread would occur and that only one follow-up treatment would be required. In contrast, I estimated that it would take 695 and 54 years to remove invasive alien plants from the Kouga and Krom catchments, respectively, at current levels of funding. I found that not only are WfW treating only a small part of the respective catchments – an observation consistent with a nation-wide assessment by van Wilgen et al. (2012) – but that where treatment does occur, it is largely ineffective.

Factors affecting the cost-effectiveness of invasive plant control

The amount of money allocated to a site had a negative influence on cost-effectiveness. In other words the more money spent on a site the less cost-effective the treatment One would have expected the opposite. I was not able to assess the quality of treatments carried out, but this unexpected result suggests that adequate levels of diligence are not being consistently maintained. The positive relationship between site distance from the project manager's office and cost-effectiveness could also imply a lack of diligence on behalf of managers in assessing the quality of remote clearing operations. More research would be required to determine the nature of constraints to WfW's ability to implement cost-effective treatments.

The other major determinant of project cost-effectiveness, not accounted for in my regression models, could be the low willingness or capacity of private landowners to conduct follow-up treatments (Le Maitre et al. 2004). WfW policy regarding interventions on private land is that landowners are contractually bound to take responsibility for site maintenance after the second follow-up treatment carried out by WfW. This did not occur in both the projects that I assessed.

The regression analysis showed that in terms of equivalent condensed hectares, treatments on sites with higher pre-treatment alien plant percentage cover were more cost-effective in comparison to less densely invaded sites. One reason could be that clearing sparse invasions could be more costly than dense ones. This however is unlikely since I controlled for treatment costs. The most likely reason is that since I had no control treatment, I could not account for the spread that would have occurred had there been no treatment. The spread rate is likely to be higher on less densely invaded sites compared to densely invaded sites (Higgins et al. 2001).

How cost-effective are the projects in the provision of ecosystem services and employment?

In terms of the value of protecting water resources, which was the main argument used for initiating the WfW programme (Koenig 2008), the high costs of the Kouga treatments suggest low cost-effectiveness in terms of invasive plant control for the provision of water from the catchment area (Le Maitre et al. 2002). On the other hand, the Krom project appears to be far more cost-effective. Underestimating the costs of major interventions, like WfW, is a frequently documented problem in both the public and private sector (Lavallo and Kahneman, 2003). A key remedy to this would be to base forecasts on actual measurements of cost-effectiveness and not solely on estimates which are often prone to optimism bias (Flyvbjerg, 2008).

In terms of the employment benefits, I found that only 30% of the total costs (excluding WfW national and provincial office costs) were spent on team wages; 20% of this went to the team leader. According to Hope (2006), a development project is deemed to be wage-efficient if it spends at least 60% of its budget on wages. The two projects I assessed fell far below this benchmark. Hope (2006) found that 60% to 65% was spent on the team wages in three WfW projects in the Limpopo province. However, it appears that Hope (2006) only examined the operational costs and did not include the costs of the local implementing agent costs nor those of national management. This implies that low cost-effectiveness in reducing invasive alien plant cover (as observed in the Kouga) cannot be justified solely in terms of the employment benefits. In terms of the quality of employment, Hope (2006) found that the programme did not select the poorest people; the projects made only a small contribution to income (<0.5%) to poor households in the project areas; the employment was highly variable and the workers were not able to find employment after exiting the programme (Knipe 2005). Some of these issues have already been raised in other programmes implemented as part of South Africa's expanded public works (McCord 2007). A better understanding is required of the cost-effectiveness of WfW in reducing poverty.

Prognosis for cost-effective control in the catchments

My study identified several problems that, if considered together, indicate that current control efforts are insufficient to prevent the on-going spread of a serious invasive species, despite significant spending. At best, the rate of spread of invasive species at a catchment scale is only slowed down, not stopped, and in many places spread continues despite clearing efforts. Even if spread could be stopped, at the current rates of clearing it would still take 54 and 695 years to clear the Krom and Kouga catchments, respectively. In addition to this, there seems to be little or no effort on the part of private landowners to maintain cleared land in a cleared state, so the cleared land is simply re-invaded. Some undoubtedly cannot afford it, and others are probably disinterested. I discuss four possible interventions that may help to improve this situation.

The first would be to prioritize that catchments within (for example) a province (Forsyth et al. 2012), and then allocate sufficient funds the highest priority catchments so that the invaded area could be cleared within a reasonable timeframe. This implies that an investment would have to be made in developing adequate plans for priority areas, and monitoring progress towards annual goals, something that is not currently done. It also implies that, in order to direct sufficient funds to priority catchments, those catchments deemed to be of lower priority would not receive funding. There would undoubtedly be resistance to abandoning clearing projects in lower priority areas, but the alternative would be to continue to operate inefficiently everywhere.

A second intervention would be to invest in improved biological control solutions. In the case of *Acacia mearnsii*, two biological control agents have already been released (Impson et al. 2011). The first, a seed-feeding weevil, has been able to reduce the seed production of *A. mearnsii* by half (and in some cases up to 78%). The second, a gall-forming fly, was established in 2006. Although it has been slow to spread, efforts have been made to assist the distribution by establishing colonies throughout the range of *A. mearnsii* in South Africa. Where it has become established, "pod production has virtually ceased" (Impson et al. 2011), but it is not yet clear whether the fly will be able to survive in a wider range of climatic conditions. Further options are available. For example, the release of a fungal pathogen on *A. saligna* has resulted in "a dramatic decline in population density and longevity of mature trees, as well as a reduction in canopy cover and seed production" (Impson et al. 2011). Similar options would be available for *A. mearnsii*, but because this tree species has commercial value in a small wattle industry, the option has to date not been seriously considered, although it should be (van Wilgen et al. 2011). An economic study of management options for *A. mearnsii* (De Wit et al. 2001) concluded that "the most attractive control option would be to combine physical clearing and plant-attacking biological control with the continuation of commercial growing activities". Under this scenario, commercial growers would have to protect their plantations from biological control agents as they currently do for other pest species.

The third intervention would be to significantly improve levels of professionalism with regard to management. There are several clear areas where a more professional approach would improve the effectiveness of management. These include the allocation of funding to adequate planning, monitoring and evaluation, activities which are currently absent, but should form part of a comprehensive strategy for control (van Wilgen et al. 2011). In addition, instead of locating sites for clearing at random (as is presently done), a more systematic approach should be adopted. An understanding of the mechanisms of spread (by means of seeds, mainly along water courses) suggests that a far better approach would be to systematically clear invasions from the top to the lower reaches of drainage courses, to prevent re-invasion of cleared sites from above. The employment of qualified ecologists could thus potentially add an increased level of professionalism to clearing operations.

Finally, it will be necessary to find a more effective way to deal with areas that have been cleared on private land. Although landowners sign agreements to maintain areas that have been cleared once WfW has completed the initial clearing and follow-up, these agreements are, by and large, not honoured. Part of this may be due to landowners simply not having the resources to cope with the required follow-up, and part may be due to the clearing not having been completed to the expected standard before handing back to the landowner. To overcome this, agreements with landowners could be tailored to suit individual situations, instead of adopting a one-size-fits-all approach. Wealthy landowners whose land is relatively lightly invaded could reasonably be expected to maintain the land in a cleared state, while relatively indigent landowners with heavily-invaded properties might reasonably expect a level of on-going state funding that would bring benefits to downstream water users. Where cleared land is to be returned to the custody of the landowner, the quality and level of clearing should be included in the landowner's agreement, and there should be concurrence that standards had been achieved prior to handover.

CHAPTER 3: DO MANAGERS' BELIEFS DIFFER FROM EVIDENCE-BASED FINDINGS AND ARE THEY WILLING TO CHANGE THEIR BELIEFS? A CASE STUDY INVESTIGATION[2]

INTRODUCTION

Since the start of this century increasing attention has been placed on the need for conservation managers to base their decisions on evidence-based findings (e.g., Sutherland et al. 2004). Despite this, a large proportion of conservation managers still do not use evidence-based knowledge in making important decisions (Pullin et al. 2004; Pullin and Knight 2005; Ntshotsho et al. 2011). Instead, they manage, as Longcore et al. (2007) suggest, by assertion, largely relying on their personal experience and common-sense. Some of the most frequently cited reasons why managers behave in this way are lack of available evidence-based findings followed by cost and time constraints (Pullin et al. 2004; Pullin and Knight 2005).

The low usage of evidence-based knowledge is seen as problematic owing to the fact that all people, including conservation managers, are prone to a range of cognitive biases such as availability, representativeness, anchoring and overconfidence (Tversky and Kahneman 1974). These biases, particularly overconfidence, can result in managers overestimating what they are capable of achieving and underestimating the likelihood of failure (Lovallo and Kahneman 2003). The use of evidence-based knowledge by managers is assumed to counteract these biases (Sutherland et al. 2004).

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[2] This chapter is being prepared for the *Journal of Environmental Management*.

Evidence-based knowledge, however, is not infallible. Thus, it is not immune to subjectivity and biases of interpretation (Hillborn and Mangel 1997). In defense of common-sense, Gigerenzer and Brighton (2009) argue that more accurate decisions can often be made with less information and processing time using simple heuristics instead of complex models. Within a conservation planning context, Cowling et al. (2003) demonstrated the strengths and weaknesses of scientific modeling and expert judgment, and suggested cross-checking them with each to improve the accuracy of decision making. Furthermore, a critical constraint – that has been given almost no attention – is whether conservation managers are actually willing to change their belief if exposed to evidence-based findings. Since acquiring evidence-based knowledge can be expensive (Grantham et al. 2009), it is important to understand if and when it changes managers' beliefs and how their biases, if any, influence their beliefs. This chapter focuses on this issue using a case study from South Africa's Working for Water (WfW) programme.

WfW is arguably the world's most ambitious alien plant control programme (Keonig 2009), yet it does not monitor the post-treatment alien plant cover of sites. Instead it only measures alien plant cover prior to a treatment (Levendal et al. 2008; van Wilgen et al. 2012). This is exacerbated by the fact that it has not established clearly defined time-based goals that it can work towards and measure (van Wilgen et al. 2012). As part of a suite of suggestions, Levendal et al. (2008) recommend that WfW monitor the post-treatment cover of its treatment sites, so that it can measure its effectiveness over time, and consequently adapt its strategies if needs be.

Chapter 2 is the first study to provide quantitative evidence of the effectiveness of clearing by WfW. It assessed the effectiveness of WfW in reducing invasive alien plant cover over a seven year period in the Kouga and Krom river catchment projects in the Eastern Cape province. The key finding was that post-treatment control was ineffective; it would take 54 and 695 years to clear the remainder of the two respective catchments assuming that no further spread would occur. In addition, it cost over 2.4 times more to reduce invasive alien plant cover in these projects than the least optimistic estimate made in previous studies (Le Maitre 2002).

In this paper, I used this opportunity, to ask three questions. Firstly, how do the initial beliefs all the WfW managers responsible for managing the aforementioned projects differ from the evidence-based findings in Chapter 2, and secondly are managers willing to change their beliefs after being exposed to these findings. These two questions centred on the historical effectiveness of WfW in reducing invasive alien plant cover in the two catchment projects as well as the managers' forecasts of WfW's future effectiveness, and the factors that underpin WfW's effectiveness. My third question focused on the financial costs of acquiring evidence-based knowledge. Specifically, I asked what proportion are these costs of the overall annual project budgets.

METHODS

Evidence-based assessment

Measuring the progress of invasive alien plant clearing

See chapter 2 for a description of the methods used to measure the progress of invasive alien plant clearing.

Statistical modelling

The statistical modelling method differed from the method used in chapter 2. I therefore describe these methods in detail in this section. I identified 29 quantitative and qualitative predictor variables indicative of biophysical, operational and landowner issues related to clearing cost-effectiveness (Table 3.1).

Table 3.1 Variables used as predictors of post-treatment invasive alien plant cover of Working for Water treatment sites in the project catchment areas.

Variable	Source
Altitude - average (m)	Department of Land Affairs
Altitude - range on site	Department of Land Affairs
Area of all sites on farm (ha)*	WIMS
Area of site (ha)	WIMS
Days between treatments – average	WIMS
Days since last treatment	WIMS
Distance to closest road (m)	Department of Land Affairs
Distance to project office (m)	GIS analysis
Landowner allows return access	Project managers
Landowner asks for follow-up	Project managers
Landowner does follow-ups	Project managers
Landowner foreign or local	Project managers
Landowner resident or non-resident	Project managers
Landowner received herbicide	Project managers
Landowner allows fire	Project managers
Number of fires	FIRMS
Number of treatments	WIMS
Person days per hectare	WIMS
Pre-treatment alien cover (%)	WIMS
Pre-treatment alien plant species	WIMS
Project domain (Kouga or Krom)	WIMS
Rainfall - annual average (mm)	Lynch (2004)
Rands (ZAR) spent per hectare	WIMS
Riparian area (%)	Department of Land Affairs
Site cultivated (yes or no)	Surveyed by authors
Slope - average (degrees)	Department of Land Affairs
Site aspect (degrees)	Department of Land Affairs
Tenure type (private or public)	Project managers
Treatment type used	WIMS

*This variable measures the total area of all the sites that fell within a landowner's property. Having more treatment sites on one property could make access easier for Working for Water but it could also make it more difficult for landowners to maintain sites. WIMS: Water Information Management System, FIRMS: Fire Information Management System.

I extracted the operational data, as mentioned, from the WfW database, and the landowner information from interviews with the project managers. I estimated the percentage riparian area of a site by buffering perennial and non-perennial rivers by 83 m and 41 m, respectively (Cullis et al. 2007). I then overlaid the site polygon data and determined the percentage riparian area. I estimated the number of fires per site by using the Fire Information Resource Management database (FIRMS, 2002). The database uses MODIS satellite imagery to record the time and location of a fire at a 1 km^2 resolution. I overlaid these data with the WfW treatment sites to determine the frequency of fire events for each site between 2002 and 2008. I recorded a fire event if more than 50% of a treatment site intersected a fire cell. I estimated the mean annual precipitation (MAP) of a site using rainfall gauge data (Lynch 2004). These data give point MAP estimates at a 0.01 degree resolution. I converted these point data to raster data and derived an average MAP estimate for each site. I used digital 1:50 000 data from the Department of Land Affairs for the slope, altitude, aspect and road data.

I used boosted regression trees (BRT) to assess the relative importance of predictor variables for estimating post-treatment invasive alien plant cover (Elith et al. 2008; Hastie 2009), since I needed an approach that was flexible enough to incorporate a large number of variables, interactions and missing values. In comparison to conventional regression tree methods, BRT fits multiple trees to the data using machine-learning algorithms. This method reduces the instability associated with single regression tree models and improves the overall predictive performance (Hastie 2009). The relative importance of the sum of the predictor variables is measured out of 100 (higher values indicate greater influence on the response), based on the number of times the variable was selected for splitting, weighted by the squared improvement the split makes to the model over all the trees (Elith et al. 2008). I used the following input settings for the BRT models: Laplacian distribution (absolute error loss); 6 000 trees were fitted to the data at a shrinkage rate (i.e. rate at which the model learns the data) of 0.005, an interaction depth of three, and six cross validation folds. I used the gbm package (Elith et al. 2008) in R 2.13.1 (R Development Core Team 2011).

Elicitation of managers' beliefs

I interviewed the WfW managers responsible for the WfW Kouga and Krom projects face-to-face in 2010. They consisted of seven operational managers and two managers with both scientific and managerial experience, namely the Krom project manager and the Kouga project manager who had been in charge of rehabilitation activities, one area manager (responsible for both projects) and the provincial manager of the Eastern Cape. The other managers included an area manager and a project manager who worked in a nearby management area, and a national WfW manager. I also included as interviewees two managers contracted by WfW to provide scientific management advice for clearing operations. All of the interviewees and me are members of the Eastern Cape Restoration Program, a WfW forum for managers and scientists to respond adaptively to project management issues.

Firstly, I firstly asked the managers questions broadly related to the historical effectiveness of WfW in reducing invasive alien plant cover for the two projects; secondly their forecasts of WfW's future effectiveness, and lastly the factors that they thought would best explain effectiveness of clearing operations.

To measure managers' beliefs regarding effectiveness of clearing invasive alien plants, I asked them to estimate the total amount of condensed invasive alien plant hectares (100% equivalent cover) at the time of the evidence-based evaluation (start of 2009) on all sites treated by WfW since 2002. Before eliciting their answer, I told them what the total condensed hectares of invasive alien plants were before the first treatment for each catchment project. I then showed them five possible post-treatment cover estimates for each catchment project on a bar plot, and told them that one of the estimates was the measurement made in the evidence-based assessment. This was done for both the Krom and Kouga projects. I also asked them what percentage of the sites – measured in the evidence-based study for both projects – had lower post-treatment than pre-treatment cover (i.e. better off than before being treated).

In the second set of questions, I asked the managers how many years it would take WfW to reduce invasive alien plant cover – to a state where only minimal maintenance work would be required – from the Krom catchment, Kouga catchment, Eastern Cape and South Africa. I asked them to give three estimates of the years required to fulfill the above: the least time (optimistic scenario), most time (pessimistic scenario) and their best estimate of the required time. When making the estimates I told them to assume that WfW capacity levels (i.e. budget and size of work force) would stay at 2009 levels.

Lastly, I asked them to list, rank and weight factors they thought would best explain the post-treatment cover of a site treated by WfW. First, I asked them to list the factors using open-ended questions. After they listed these factors, I gave them a list of factors used in the evidence-based study and asked them if they wanted to update their list after seeing the evidence-based list. I then asked them to choose their top ten factors out of the factors that they listed, and to rank them from highest to lowest. I then asked them to weight each factor out of ten in terms of its relative importance, starting at 10 for their first rated factor. I then summarized the responses into themes using thematic coding based on the grounded theory approach (Creswell 2009; Birks 2010). I weighted each theme as a percentage, by dividing the sum of the scores given for each theme by the sum of all the themes scores. Lastly, I allotted each of the themes into broad categories.

Presenting and explaining the results to the managers

After I elicited their prior beliefs, I presented and explained the results of the evidence-based study to each manager individually. I then asked each manager if they wanted to change their belief after seeing these results. Three of the managers (national manager and the two scientific managers) saw preliminary findings for the descriptive evidence-based results; I therefore did not ask them these questions (indicated as N/A in the results). It is important to note that I did not present the managers with my time based estimate from chapter 2, as I had not made those estimates at that time. All the managers gave full-consent before they were interviewed.

Cost estimates for implementing the evidence-based assessment

I made cost estimates for implementing the evidence-based assessment based on the inputs (labour and capital) required to carry out the following activities: (1) collecting and preparing the site information and planning the helicopter flight plans; (2) photographing the sites from the helicopter; (3) classifying the invasive alien plant cover based on the photographs and (4) processing and analyzing the data. I assumed that these activities would be carried out by one technician, with the exception of one extra person to pilot the helicopter. I estimated the cost required to assess all the sites (n=740) across the two projects; the average cost per site as well as the cost displayed as a proportion of the total average annual budget expenditure (spent during the assessment period). I incorporated overhead costs made up of specifically management and implementing agent fees into the total cost estimate. All costs were converted to 2010 ZAR using the consumer price index (1 US$ = approximately ZAR 7.4).

RESULTS

Historical effectiveness in reducing invasive alien plant cover

The evidence-based assessment quantified the post-treatment extent of invasive alien plant cover as 755 condensed ha (100% equivalent cover) in the Kouga catchment (pre-treatment cover was 888 condensed ha) and 300 ha in the Krom (pre-treatment cover was 1 125 condensed ha). Overall, the managers underestimated the post-treatment invasive alien plant cover of the Kouga sites and overestimated it for the Krom (Figure 3.1a). The exceptions for the Kouga were the project managers in the Kouga and Krom. For the Krom, on the other hand, the area manager for the two catchments chose the correct estimate for the post-treatment cover along with the provincial director and a project manager from another catchment in the Eastern Cape. All the managers whose prior belief differed from the evidence findings changed their belief to correspond to these after being shown the evidence-based data.

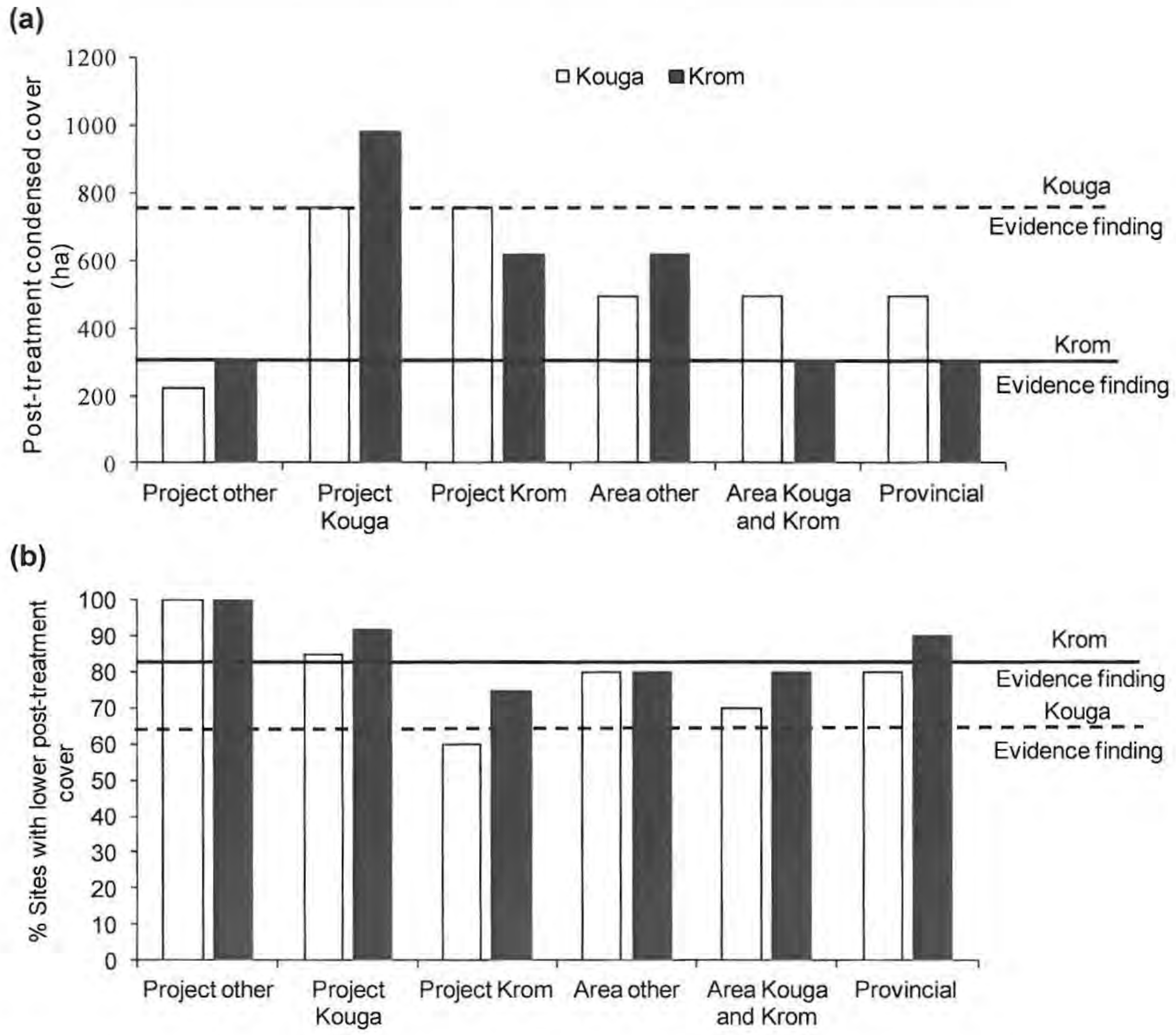
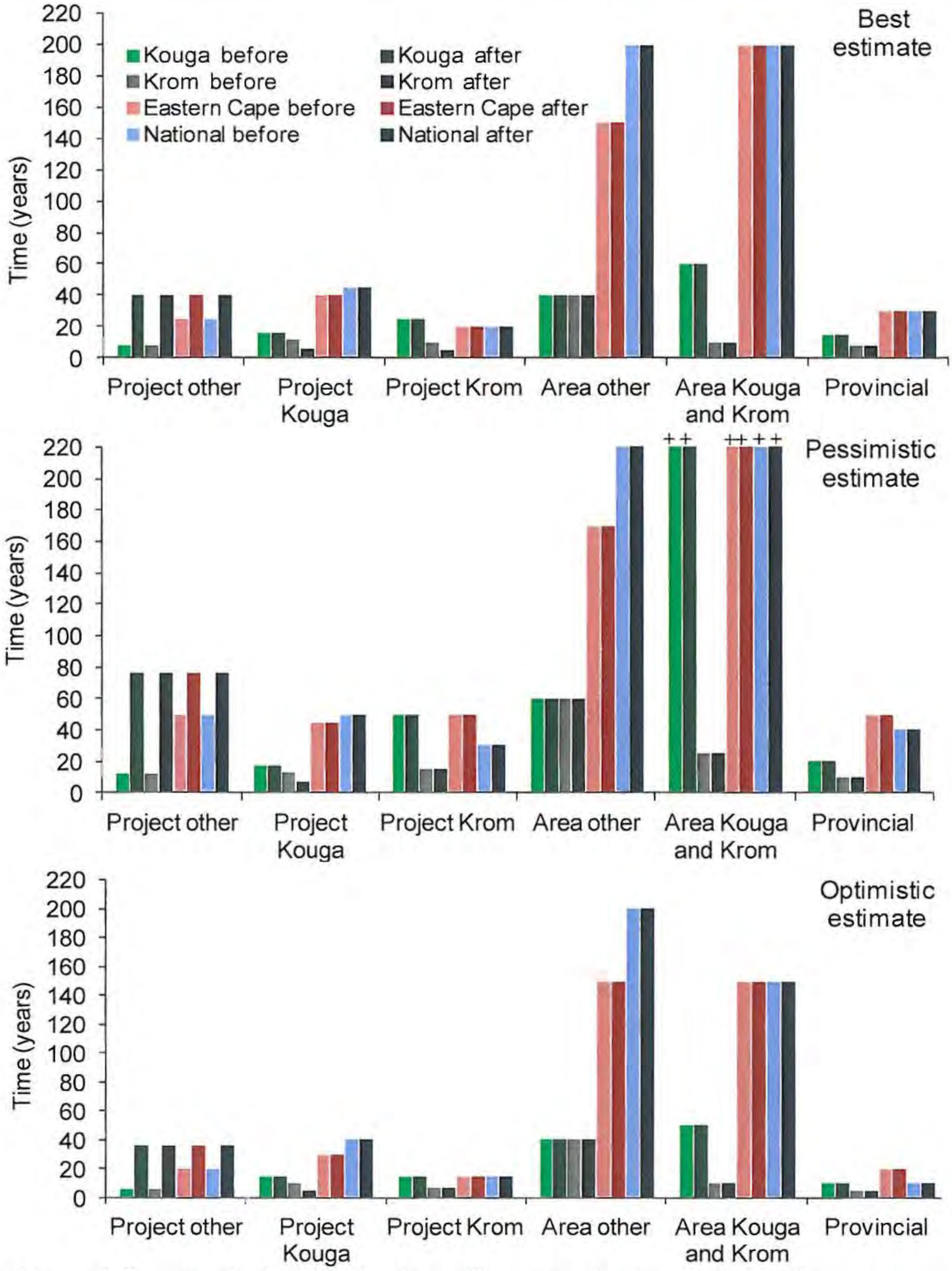


Figure 3.1 Comparison of each manager's estimates prior to being shown the respective evidence-based findings. The evidence-based findings are displayed with horizontal lines in both figures. (a) Shows their estimates of the total sum of post-treatment 100% equivalent invasive alien plant cover (condensed ha) in the two catchment projects (b) Shows their estimates of the percentage of sites with post-treatment alien plant cover lower than pre-treatment cover (i.e. better off than before first treated). Before making the estimates shown in (a) the managers were shown a bar plot with the alien cover before the first treatment on the Kouga and Krom (888 and 1 125 condensed hectares, respectively) as well as six estimates one of which they were told was the evidence-based measurement (the estimates ranged from 50 to 1 240 condensed ha for the Kouga and 50 to 1 450 condensed ha for the Krom).

The evidence-based study found that only 63.9% of Kouga sites and 82.8% of Krom sites had a lower post-treatment cover of invasive alien plants than pre-treatment (i.e. were now better off than before being treated). All of the managers believed that the Krom had a higher or equal percentage of sites with lower invasive alien cover post-treatment than pre-treatment (Figure 3.1b). Generally, managers overestimated effectiveness in the Kouga but were reasonably accurate in their estimate for the Krom. The closest prior estimate to the evidence-based finding was made by the Krom project manager, followed by the Krom and Kouga area manager. All the managers whose prior belief differed from the evidence based findings were willing to change their belief to correspond to these after being shown the evidence.

Forecasts of future effectiveness in reducing invasive alien plant cover

With regard to the managers' best estimate (Figure 3.2) of the time required to reduce invasive alien plant cover to an easily maintainable state from the respective areas, the area managers were less optimistic than the rest of the managers. Most of the managers forecasted that the Krom would take less time to clear than the Kouga. No managers – with the exception of one project manager – increased their forecasts of the time it would take to clear the remaining areas. The Kouga and Krom project managers reduced their estimate of the time it would take to clear the Krom catchment but did not change any of their estimates of the time needed to remove invasive alien plants from the Kouga catchment.



+ Manager believes here that invasive alien plants will never be reduced to a minimal easily maintainable state.

Figure 3.2 Managers' estimates before and after being shown the evidence-based findings (Figure 3.1), of the years required for WfW to reduce invasive alien plant cover – to a state where only minimal maintenance work would be required – from the Krom catchment, Kouga catchment, Eastern Cape and South Africa. I asked them to give three estimates of the years (caption contd.) required to fulfil the above: the least time (optimistic scenario), most time (pessimistic scenario) and their best estimate of the required time. When making the estimates I told them to assume that WfW capacity levels (i.e. budget and size of work force) would stay at 2009 levels.

Factors that underpin effectiveness

Beliefs before being shown the evidence-based model

The highest weighted category identified by managers overall was the quality and capacity level of firstly the management and then the teams, followed closely by the willingness of landowners to maintain sites (Figure 3.3 and 3.4). Biophysical themes relating to the type of invasive alien plant cover and suitability for growth were weighted lower than the human related themes. The manager to differ the most from this trend was the area manager of the Krom and Kouga projects (Figure 3.4). This manager rated landowner willingness followed by site access as the most important categories.

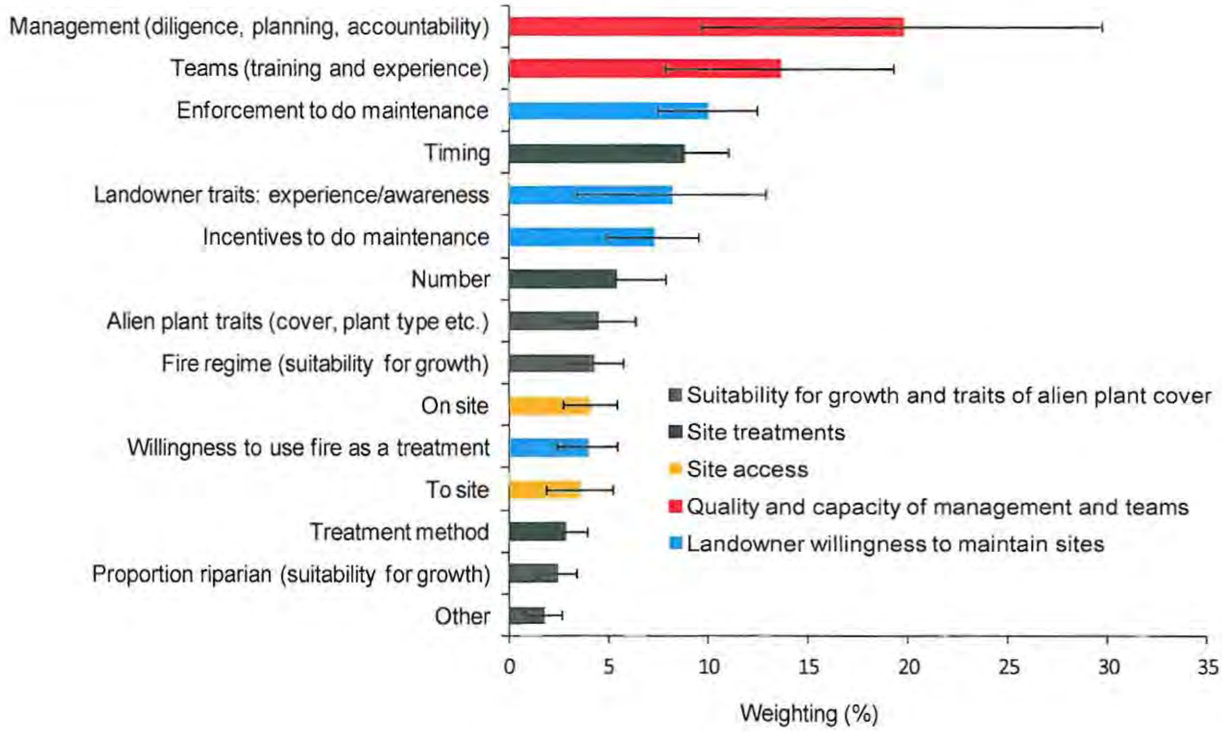


Figure 3.3 Average weight (i.e. relative importance) given to variables (grouped into themes and categories) by managers – before being shown the evidence-based model (Figure 3.5) – predicting the post-treatment invasive alien plant cover for a site treated by Working for Water. The weight is a percentage (sum of 100%) calculated by dividing the sum of the scores given for each theme by the sum of all the themes scores. Error bars depict standard error of the mean.

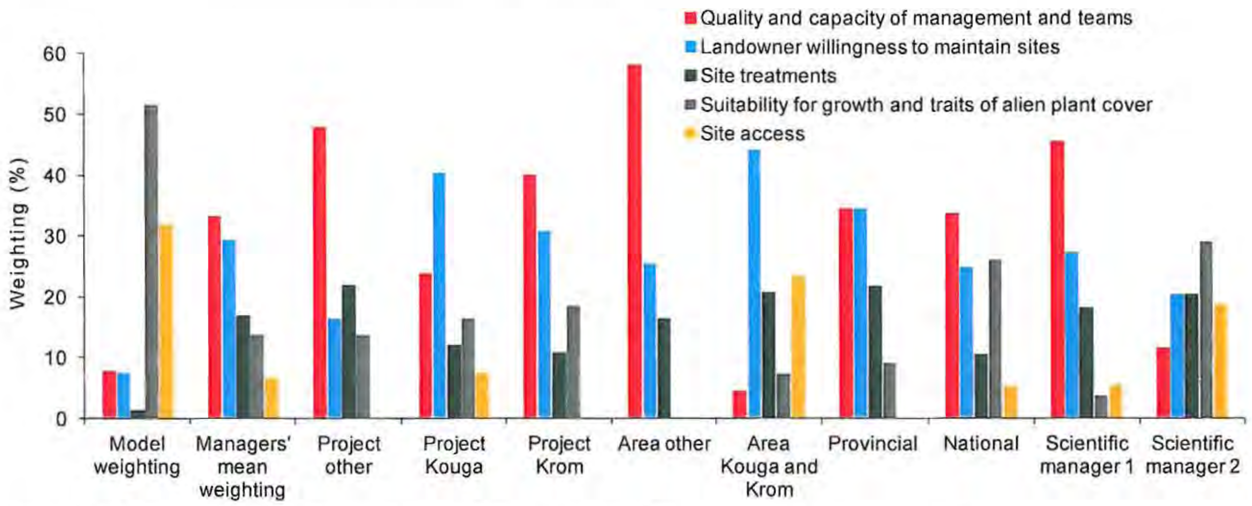


Figure 3.4 Comparison of the model weighting (Figure 3.5), managers' mean weighting (Figure 3.3) and each managers weighting of variables grouped into categories explaining the post-treatment invasive alien plant cover on sites treated by Working for Water (i.e. a proxy for effectiveness).

Evidence-based model findings

Overall, variables related to access to sites by teams and pre-treatment cover emerged as the most important predictors (Figure 3.5). Thus, altitude, distance to project office and area of sites on a landowner's property were the second, third and fourth most important variables, respectively. Pre-treatment cover (%), rands spent per ha, area of site (smaller sites are more densely infested) – all related to pre-treatment cover - emerged as the first, fifth and sixth most important predictor, respectively. Site slope was the seventh most important predictor but correlated negatively with post-treatment cover, possibly because steep slopes have shallow, droughty soils that limit rates of invasive alien plant re-growth. Variables reflective of suitability for invasive alien plant growth, landowner traits and management diligence had low importance, overall.

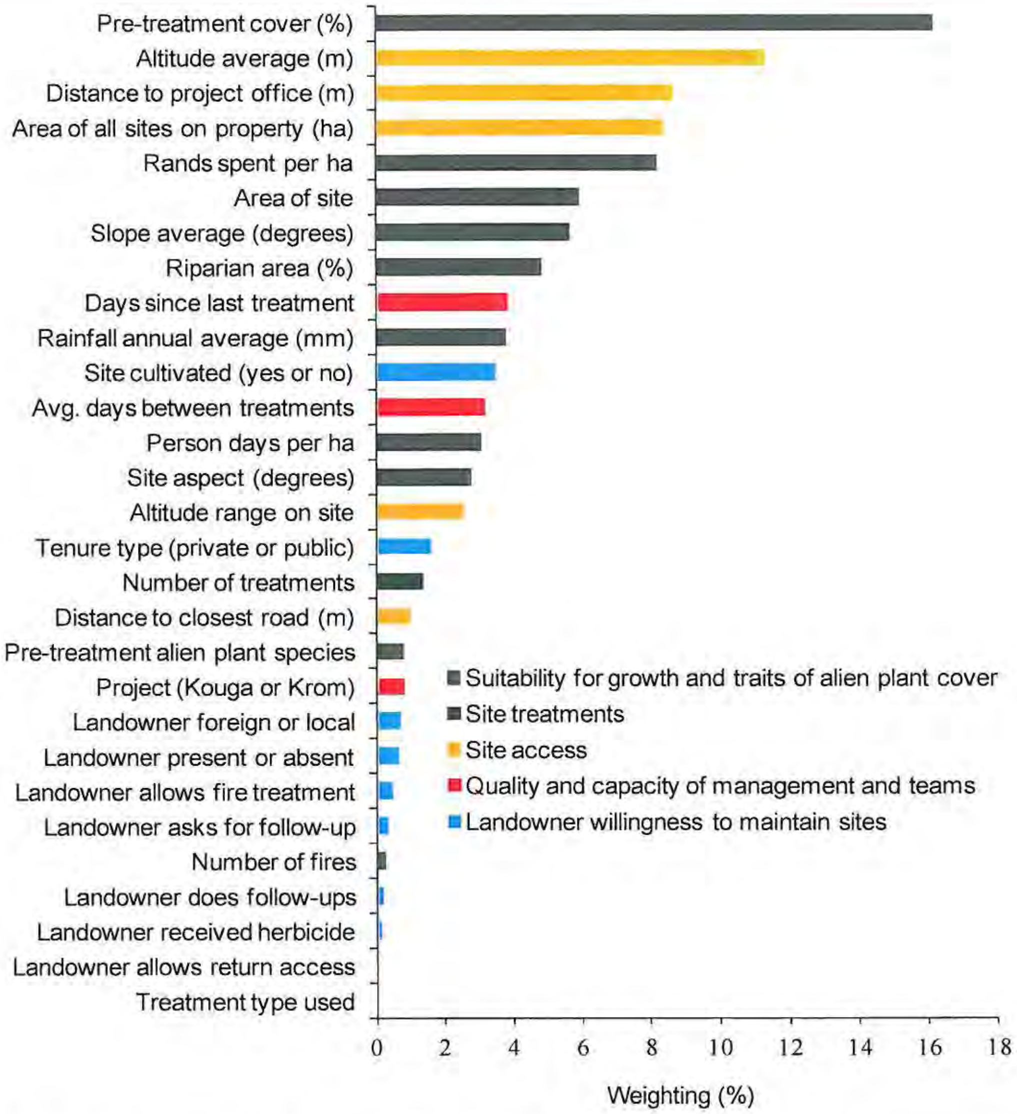


Figure 3.5 The evidence-based model's weighting of variables predicting the post-treatment invasive alien plant cover of the sites (n=740) treated by Working for Water in the catchment projects during 2002 and 2008. The model is a boosted regression tree and used cross validation folds. The explained variance = 33.2%; standard deviation = 0.509 and RMSE = 0.817. The weighting (or variable importance) is measured out of 100 (higher values indicate greater influence on the response variable) and determine the relative importance of a variable by the number of times it is selected for splitting, weighted by the squared improvement the split makes to the model over all of the 6 000 trees that were used to make the prediction

Managers' beliefs after being shown the evidence-based model

With the exception of one scientific manager, there was no change in belief by the managers after seeing the results of the above scientific assessment. This scientific manager only made minor changes by replacing site access with a theme related to incentivizing landowners to maintain sites.

Cost estimates for collecting evidence-based knowledge

I estimated that monitoring the post-treatment invasive alien plant cover of all the sites across the two catchment projects would require a small fraction of the two projects' annual expenditure (Table 3.2). Even if the sites were monitored every year it would still require less than 2% of the annual budget.

Table 3.2 Estimates of the inputs and costs (ZAR, South African Rands) needed to complete the activities undertaken in the evidence-based assessment described in this paper. The estimates show the total costs to assess all 740 of two projects sites, the cost per a site as well as the proportion of the total annual budget that would be required if carried out at one, two or three year intervals.

					% of total annual expenditure (2.75 million ZAR) if every:		
Activity	Time (hours)	Cost per hour (ZAR)	Total cost (ZAR)	Cost per site (ZAR x10^{6})	1 year	3 years	5 years
Preparation	40	100	4 000	5.4	0.15	0.05	0.03
Photographing the sites	4	5 000	20 000	27.0	0.73	0.24	0.15
Classifying the alien plant cover of sites	160	100	16 000	21.6	0.58	0.19	0.12
Processing and analysing data	40	150	6 000	8.1	0.22	0.07	0.04
Total	244	N/A	46 000	62.2	1.67	0.56	0.33

DISCUSSION

As mentioned in chapter 2, previous estimates of WfW's cost-effectiveness were based on the assumption that post-treatment cover would be minimal (Le Maitre et al. 2002; Marais and Wannenburgh 2008). In contrast to this, the evidence-based study found high levels of re-invasion across treatment sites. Many sites were worse-off than before being treated. The managers – especially the local catchment area and project managers – knew that this was the case, as reflected in the prior estimates. This suggests that the closeness of a manager to a project may impact on their estimation accuracy. The managers whose prior beliefs differed were willing to change their beliefs after seeing the evidence-based findings.

Surprisingly however – despite knowing that WfW had not been effective in the catchments over the past seven years – the managers on the whole were optimistic in their forecasts of WfW's future effectiveness in the catchments. And even after being shown the evidence-based findings of high invasive alien plant re-growth after clearing, they still did not want to adjust their optimistic forecasts. Their best estimates after seeing these evidence-based findings ranged from 8 to 60 years for the Kouga and 8 to 40 years for the Krom, whereas in Chapter 2 I estimated that it would take 695 and 54 years just to remove the current extent of invasive alien plant cover in the Kouga and Krom, respectively, ignoring further spread. It however is important to re-iterate, as mentioned in the methods, that I did not show the managers these estimates of how long it could take to clear the catchments.

Why might the managers be optimistic in their forecasts for the catchments and unwilling to change their beliefs? The first explanation – frequently documented in the planning and psychology literature – could be optimism bias (Sharot et al. 2007; Flyvbjerg 2008). Decision makers tend to overestimate what they are of capable of achieving and seldom consider their, or others, historical effectiveness when making forecasts (Weinstein 1980). To curb this tendency, Lavallo and Kahneman (2003) recommend basing forecasts on recordings of historical effectiveness called reference class forecasting. Evidence-based knowledge can play an important role in this regard by providing objective estimates. The second possible explanation could be that of the anchoring effect. According to Tversky and Kahneman (1974), when making estimates, people are anchored to their initial reference point – in this case their prior estimate of the time required to clear invasive alien plants from the catchments – and then make incremental adjustments based on the new information. This obviously can lead to poor decision-making when their initial beliefs are inaccurate. However it can be useful if the new information is spurious or high levels of uncertainty. Thirdly, the managers could have found the task of forecasting the time required to clear the catchments difficult and complex thus resulting in them sticking with their original estimates.

With regard to the factors explaining the extent of post-treatment invasive alien plant cover (the proxy for effectiveness) none of the managers – with the exception of a scientific manager – changed their beliefs after being shown the evidence-based findings. The most likely reason for this was that the evidence-based model could not effectively measure the relative importance of variables such as management quality and landowner willingness. The sample size of only two projects was too small to measure the project-level variation of these variables. Interestingly, the managers rated their own performance as the single most important factor in explaining the effectiveness of WfW, particularly that of project managers. One possible explanation for this could result from the bias as an illusion of control, following the terminology of Langer (1975). It is well reported that people tend to be overly confident in their ability to control and impact on events that are often, in reality, out of their control (Presson and Benassi 1996). Further studies are needed to determine whether success is primarily attributable to management performance or if there are other factors that are beyond the control of the managers.

This chapter highlights the importance of evidence-based knowledge for learning and adaption. It also draws caution to the fact that sharing and explaining this information to the managers might not be enough for learning to occur. Managers need to be made aware of decision making biases to which all people are sometimes prone and how to overcome them. In addition, where there are conflicts of interest involved it would seem more appropriate to rely on evidence based findings. Thus, WfW urgently needs to monitor the cost-effectiveness of its projects and understand what causes this in different contexts. As argued in chapter 2, this information is not only vital for planning purposes but also for holding its implementing agents accountable and properly incentivizing managers and teams.

One of the concerns with monitoring and evaluation work is the opportunity cost involved in not spending the money on action (Grantham et al. 2009). However, the fact that it would only cost between 0.33% and 1.67% of the two projects' annual budgets to assess all sites (depending on the frequency of the monitoring) means that in WfW's case this should not be a concern. These costs could be cut even further if new technologies such as unmanned aerial vehicles were used for monitoring instead of a helicopter.

CHAPTER 4: ASSESSING THE COSTS AND BENEFITS OF RESTORATION SENARIOS FOR ALIEN PLANT INVADED RIPARIAN AREAS IN SOUTH AFRICA[3]

INTRODUCTION

Relative to other invasive plant control approaches, such as mitigation or preventative measures – ecological restoration is costly. This is because it treats the symptom and not the cause of landscape invasion (Prach and Hobbs 2008; Haisfield et al. 2010). For example the most cost-effective approach is prevention, followed by early detection and eradication (Hulme 2006). When the invasive population is established, biological control can be highly effective (van Driesche et al. 2010; de Lange and van Wilgen 2010); however, in most cases, costly clearing treatments are also required (Pyšek and Richardson 2011). Thus it is important to assess not only the effectiveness of treatments but also the relative costs so that scarce resources can be put to their best use (Naidoo et al. 2006; Wilhere 2008; McCarthy et al. 2010; Moilanen and Arponen 2011; Murdoch et al. 2007; Underwood et al. 2008). Despite the importance of this, few studies have assessed the costs of restoring plant invaded areas (Kettenring and Adams 2011).

In South Africa, some alien plants heavily invade riparian areas and in doing so, impact negatively on water resources, riverine functioning and biodiversity (Le Maitre et al. 2000; van Wilgen et al. 2008). Growing awareness of the problem resulted in the formation of the state-funded WfW programme 1995. Being a public works programme, an important part of its mandate is to provide employment for South Africa's rural poor. As a result, the main restoration treatments involve labour intensive removal and follow-up treatments (Holmes et al. 2008). In densely invaded riparian areas, mirroring the international trend (Kettenring

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[3] This chapter is being prepared for *Restoration Ecology*.

and Adams 2011), there has been debate over whether removal alone will be sufficient for restoration or if active restoration treatments are also required, such as re-vegetation (Holmes et al. 2008). Despite the importance of this debate in South Africa, and globally, few studies have assessed the costs and benefits of the restoration treatment alternatives (Kettenring and Adams 2011).

Furthermore, as demonstrated by Aronson et al.'s (2010a) review of the ecological restoration literature, few studies assess and demonstrate the socio-economic benefits of restoration interventions. They argued that doing so is a vital step toward bridging the divide between research and implementation, and ultimately receiving broader societal support for ecological restoration. For example, as demonstrated in chapter 2 private landowner buy-in is vital for the effective long-term control of invasive plants. A possible impediment for receiving landowner buy-in in this case is the fact that the cost of control exceeds the financial benefits that they can derive from removing invasive plants on their properties.

In an attempt to start filling the above gaps, I compared the costs and financial benefits of three restoration scenarios: namely removal, active re-vegetation and containment. For each scenario, with the exception of containment, I included a high-efficiency and low-efficiency sub-scenario. I based the latter sub-scenario estimates on measurements of cost-effectiveness in the WfW programme and the former on estimates using work-study methods (Currie and Faraday 1977). I focused on riparian areas densely invaded by *Acacia mearnsii* (black wattle) in the Grassland and Fynbos biomes. This invasive tree, originating in east Australia, is currently South Africa's most prolific invader in terms of extent and impact on ecosystem services and native biodiversity (de Wit et al. 2001), and as a result WfW have spent the most money treating this species (van Wilgen et al. 2012).

The purpose of the scenario analysis was to compare the potential relative cost-effectiveness of the treatment scenarios as well as their financial feasibility. I therefore did not attempt to estimate the total economic value of the interventions. Instead, I focused on the most commonly assessed ecosystem services that deliver financial benefits: water and livestock grazing (van Wilgen et al. 2008).

METHODS

Study area background

The Grassland and Fynbos biomes cover approximately 29.4% of South Africa's land-surface area, 24.1% and 5.3% respectively (Figure 4.1). The Grassland biome has a higher rainfall, and agricultural potential compared to the Fynbos biome. Fynbos vegetation is a sclerophyllous shrubland associated with nutrient poor, sandy soils (Cowling 1992). Both biomes are prone to regular fire events and are mostly treeless (Mucina and Rutherford 2006) – resulting in their susceptibility to invasion by alien trees – even in the absence of anthropogenic disturbance (Richardson and Cowling 1992). Invasive plants are one of the primary threats to the high levels of biodiversity and species endemism in this biome (Cowling and Hilton-Taylor, 1994).

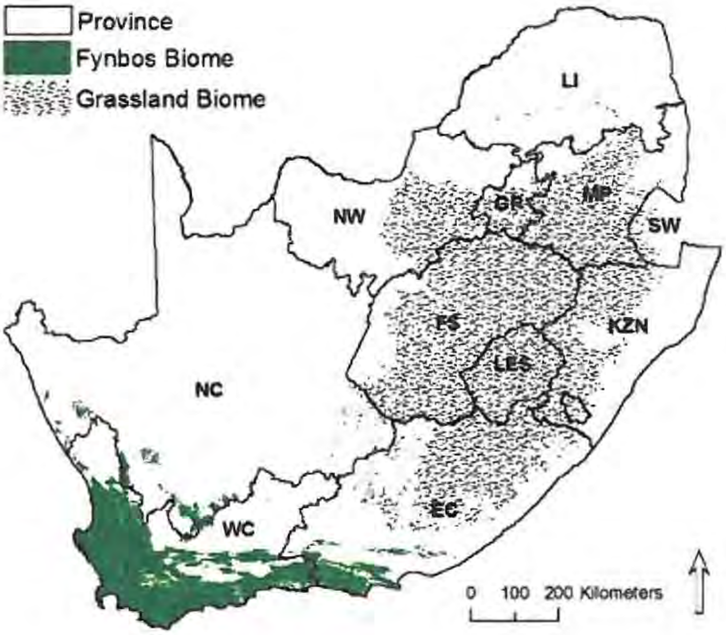

Figure 4.1 Location of the Grassland and Fynbos biomes, and province boundaries within South Africa.

Treatment scenario details and cost estimation

I calculated costs for each scenario by estimating the present value of the costs required to treat a hectare of land densely invaded by *A. mearnsii* over a thirty-year period. I used a discount rate of 4% and adjusted all costs for inflation to 2011 ZAR, using the consumer price index (1 US$ = approximately ZAR 7.4).

Scenario 1: Alien plant removal

The effective control of coppicing species like *A. mearnsii* requires felling, followed immediately by the careful application of herbicide to the cut stems. This kills the plant and thus prevents coppicing. Clearing also stimulates the germination *en masse* of seeds from a large and persistent soil-stored seed bank (Holmes et al. 2008). Numerous and timely follow-up treatments are required to treat both seedlings and coppice re-growth by spraying with herbicide, and is compounded when previous treatments were poorly executed. Re-growth taller than 1.8 m is unaffected by herbicide and plants must be re-felled, which is far more costly (Holmes et al. 2008).

High-efficiency removal sub-scenario

In this scenario, I assumed that carefully applied clearing treatments would result in the successful removal of *A. mearnsii*. In order to minimize native plant mortality, follow-up treatments would use hand-pulling and lopper treatments instead of the conventional foliar herbicide applications currently carried applied by WfW. I used WfW's norms and standards data to estimate these costs (Neethling 2010). I assumed easy terrain working conditions, along with minimal travel and walk-in times (see Appendix, Table A.1 for details).

Low-efficiency removal sub-scenario

I based my estimates on the only assessment to date of WfW's cost-effectiveness in reducing alien plant cover over time (Chapter 2). The study assessed the reduction in alien plant cover over a seven-year period in two large WfW projects, located in two river catchments in the Eastern Cape province. The bulk of the treatments involved initial removal and follow-up treatments using foliar herbicide applications. From this assessment's data set, I first selected sites that had a riparian area of at least 50%. From this selection, I selected sites where *A. mearnsii* was the dominant species and where the baseline cover (i.e. pre-treatment cover) was greater than 50%, and that had received at least two treatments. I calculated the treatment cost by estimating the total cost spent on the area divided by the reduction in alien plant condensed hectares during the treatment period between 2002 and 2008. The condensed hectares were derived by converting the estimates of plant cover to 100% equivalent cover ("condensed ha"), using the formula: $C = d/100 \times A$, where C is the area expressed as condensed ha, d is the density (% cover), and A is the area in ha that was treated.

Scenario 2: Active re-vegetation

The active re-vegetation treatment scenario differs from the removal scenarios in that after the initial felling of the *A. mearnsii* trees, the area is actively restored using native plant species. Follow-up treatments include hand pulling and lopping of alien plant re-growth. In both sub-scenarios, I used a planting density of one stem per square meter, and in order to account for plant mortality I assumed that 30% of the fynbos and none of the grassland planted area would require follow-up (see Appendix, Table A.2 for details). This was based on the assumption that active re-vegetation would suppress alien plant re-growth. I based the estimates on two WfW pilot projects that were established to test the operational feasibility of restoration methods, located in the Kouga and Albany catchment areas in the Eastern Cape.

Active re-vegetation high-efficiency sub-scenario

In the high-efficiency scenario, I assumed that the terrain would be easily accessible and no production delays would occur. Lacking data on norms and standards, I made cost estimates using work-study observations in the Kouga pilot restoration project. For the types of plants used, I assumed an equal combination of splits (graminoids), seeds and rooted cuttings for fynbos restoration. For the Grassland biome, I assumed an equal combination of splits and cuttings.

Active re-vegetation low-efficiency sub-scenario

I estimated costs for this scenario by dividing the total restoration costs by the number of stems planted during the Kouga pilot project to derive the cost per stem. I excluded the scientific and other specialist technical costs. It is important to note that the cost estimates are likely to be an overestimate in this scenario. Firstly, the accessibility to the site was difficult and secondly being a pilot project many of the tasks were novel and hence numerous production delays occurred.

Scenario 3: Containment

This scenario involves containing the extent of the invasion by only removing alien growth that spreads from the invaded area; therefore, I assumed that a small maintenance cost would be required. I assumed that the existing invaded area would increase in density but not in spatial extent. I used WfW's data on norms and standards to estimate the costs (Neethling 2010). Lastly, I needed to account for the densification of the *A. mearnsii* stands over time. I assumed that the sites had a current alien plant cover of 75% allowing for 25% densification at a rate of 10% per annum. I based this growth rate on an estimate used by Le Maitre et al. (2002).

Identifying the extent of the *Acacia mearnsii* riparian invasion

I used a preliminary version of the National Invasive Alien Plant Survey (NIAPS) data set (Kotze et al. 2010) to determine the riparian extent of *A. mearnsii* invasions within the Grassland and Fynbos biomes, as delimited by Mucina and Rutherford (2006). The data are summarized per quaternary (fourth order) catchments and show estimates of 100% canopy cover (condensed ha, see above). The NIAPS mapped invasions in natural areas, excluding transformed areas such as urban, mining and cultivated areas. Furthermore, for riparian areas it only mapped areas along South Africa's main rivers (mapped at a 1: 250 000 scale); therefore, it is likely to be an underestimate of the actual riparian area. I selected quaternary catchments that fell within the Grassland and Fynbos biomes and summarized these per Water Management Area.

Next, I determined the fraction of the area that might require a change in strategy from the conventional WfW removal and follow-up method. Holmes et al. (2008) recommended only using active re-vegetation treatments for areas with an alien plant cover of >50% and that had experienced at least two fires. Owing to the coarse resolution of the NIAPS data, I decided rather to base this selection on my Chapter 2 data, as described above. From this, I estimated that 37.3% of invaded *A. mearnsii* riparian areas had a post-treatment cover higher than 50%. I then selected sites that were given at least two treatments and had not been treated for at least a year. I did this to determine the fraction of sites where treatments were ineffective. I based this on whether or not the site had a higher alien plant cover than before being treated. 71.7% of the sites had a current cover that exceeded their respective baseline cover. Thus, based on the above calculations, I selected 26.7% of the *A. mearnsii* invaded area for each quaternary area selected above.

Estimating the financial benefits

For evaluating the financial feasibility of the treatment scenarios, I calculated net present values using a cost-benefit analysis with a discount rate of 4% and adjusted all costs for inflation to 2011 ZAR, using the consumer price index (1 US$ = approximately ZAR 7.4). I assumed that the financial benefits would be the same for above-mentioned scenarios.

Stream flow reduction

I calculated incremental stream-flow reduction using the Le Maitre et al. (2002) biomass equations, which assume that higher relative biomass levels of tall alien plant trees – such as *A. mearnsii* - consume more water than the native vegetation in the Grassland and Fynbos biomes. Based on this, I assumed that the incremental annual water use of *A. mearnsii* in the Fynbos biome was 3 917.9 m^3/ha and 5 945.5 m^3/ha in the Grassland biome. To account for zero flow months, where potential evaporation is limited, I used the WR2005 data set (Middleton and Bailey 2005).Finally, I based the water price on the inflation-adjusted water tariffs taken from Marais and Wannenburgh (2008) (See Appendix, Table A.3). I assumed that 75% of the water was utilizable based on the assumption made by Cullis et al. (2007).

Grazing benefits

I calculated loss in grazing potential using the Scholes (1998) data set. It identifies grazing potential as livestock units (LSU) per square kilometer. I used the assumption of van Wilgen et al. (2008) that densely invaded areas will decrease grazing potential by 80%. From this, I could then calculate the loss of LSU for the study area. I estimated the annual value of a LSU (ZAR 1 401.9) based on the inflation- adjusted gross average value of a LSU (Department of Agriculture 2003).

RESULTS

Spatial extent of *Acacia mearnsii*

Of the overall riparian *A. mearnsii* invasion in South Africa, according to the preliminary NIAPs dataset, 52.8% was located in the Grassland and Fynbos biomes (Figure 4.2a-b). The Grassland biome harbors the majority (78.1%) of this invasion. The riparian invasion represents a far lower fraction (7.0%) of total landscape invasion (Figure 4.2b). In terms of Water Management Areas, the grassland regions of the Mzimvubu and Mvoti contained over 43% of the total riparian condensed hectares (Figure 4.1b; see Appendices). Based on my assumptions, 5 119 hectares would require a change in treatment strategy from the conventional removal treatment. This problem area would therefore represent only a small fraction of the total *A. mearnsii* invasion in the two biomes (<2%).

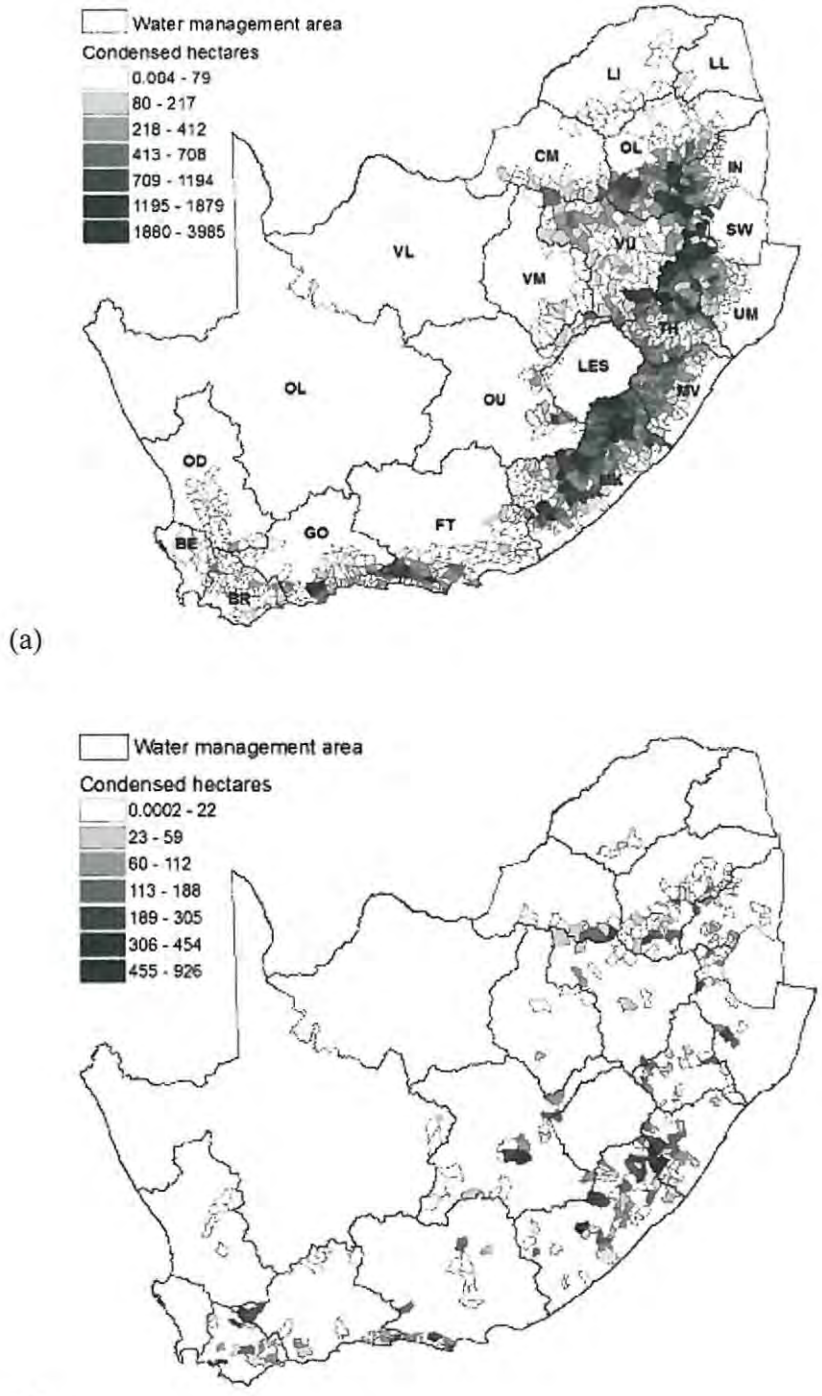

Figure 4.2 Cover represented in condensed hectares of *Acacia mearnsii* in (a) landscape and (b) riparian areas per quaternary catchment within the water management areas (see Appendix, Table A.4 for numeric values)

Financial benefits

Surface water run-off

The average annual potential benefits per hectare were far greater in the Grassland biome (ZAR 1 139) compared to the Fynbos biome (ZAR 119) (Table 4.1). This was because of the higher potential surface water loss and water price in the Grassland biome compared to the Fynbos biome.

Table 4.1 Estimated present value (ZAR/ha) of the water and grazing benefit flows over a 30 yr. period at a discount rate of 4% per Water Management Area within the Grassland and Fynbos biomes.

Water management area	Water per yr.	Grazing per yr.	Present value per ha
Breede	97	60	1 456
Crocodile and Marico	409	125	4 942
Fish to Tsitsikamma	215	77	2 705
Gouritz	122	56	1 653
Inkomati	288	95	3 540
Limpopop	409	21	3 983
Lower orange	99	89	1 738
Middle Vaal	489	145	5 866
Mvoti to Umzimkulu	870	141	9 345
Mzimvubu to Keiskamma	1 483	167	15 264
Olifants	1 463	100	14 457
Olifants/Doorn	19	34	489
Thukela	716	162	8 123
Upper Orange	169	177	3 199
Upper Vaal	4 655	114	44 113
Usutu to Mhlatuzu	818	114	8 628
Grassland mean	1 139	134	11 771
Fynbos mean	119	53	1 587
Total mean	931	117	9 698

Grazing gain

The Fynbos biome had a substantially lower potential grazing value compared to the Grassland biome (Table 4.2). On average, the grazing capacity was 10.44 LSU/km^2 for the Grassland and only 4.71 LSU/km^2 for the Fynbos biome. This amounted to an average potential gain of ZAR 134 and ZAR 53 per hectare per annum for the two biomes respectively (Table 4.2).

Net ecosystem service benefits

The net ecosystem service benefit equated to ZAR 9 697 per hectare over the evaluation period, with the bulk of this consisting of water benefits. The Grassland biome had a far higher potential annual benefit per hectare of ZAR 11 771 compared to the Fynbos biome (ZAR 1 587). The present value of the total aggregate annual benefit would be ZAR 50.4 million over the thirty-year evaluation period (Table 4.2).

Treatment costs

The present value of the treatment costs varied greatly. The low-efficiency removal costs was ZAR 58 732/ha in contrast with the high-efficiency cost of ZAR 12 145/ha. The observed active re-vegetation costs were relatively high at ZAR 132 373/ha and ZAR 105 887/ha in the Fynbos and Grassland biomes respectively. The predicted high-efficiency active re-vegetation scenario were orders of magnitude lower averaging ZAR 31 202/ha for the two biomes. As expected the containment treatment scenario costs were substantially lower at ZAR 759/ha (Figure 4.2).

Table 4.2 The present value of the total and average treatment costs per hectare (ZAR = South African rands; 1 US$ = approximately 7.4 rands) over a 30 yr. period at a discount rate of 4%. The results are shown for each Water Management Area within the Grassland and Fynbos biomes in 2011-equivalent ZAR.

Water management area	Low efficiency	High efficiency	Low efficiency	High efficiency	Containment
Breede	58 732	12 145	132 373	33 107	759
Crocodile and Marico	58 732	12 145	105 887	30 715	759
Fish to Tsitsikamma	58 732	12 145	123 025	32 262	759
Gouritz	58 732	12 145	131 269	33 007	759
Inkomati	58 732	12 145	105 887	30 715	759
Limpopop	58 732	12 145	105 887	30 715	759
Lower orange	58 732	12 145	105 887	30 715	759
Middle Vaal	58 732	12 145	105 887	30 715	759
Mvoti to Umzimkulu	58 732	12 145	105 887	30 715	759
Mzimvubu to Keiskamma	58 732	12 145	105 887	30 715	759
Olifants	58 732	12 145	105 887	30 715	759
Olifants/Doorn	58 732	12 145	132 373	33 107	759
Thukela	58 732	12 145	105 887	30 715	759
Upper Orange	58 732	12 145	105 887	30 715	759
Upper Vaal	58 732	12 145	105 887	30 715	759
Usutu to Mhlatuzu	58 732	12 145	105 887	30 715	759
Grassland mean (total)	58 732	12 145	105 887	30 715	
	(234.9)	(48.6)	(423.4)	(122.8)	759 (3.0)
Fynbos mean (total)	58 732	12 145	132 373	33 107	
	(65.8)	(13.6)	(148.3)	(37.1)	759 (0.8)
Total mean (total)	58 732	12 145	111 279	31 202	
	(300.7)	(62.2)	(159.9)	(159.9)	759 (3.9)

Net present value of the treatment scenarios

With the exception of the high-efficiency removal scenario (ZAR -2 447/ha), the net present costs far exceed the benefits of the treatments across all the Water Management Areas (Table 4.3). The observed low efficiency removal scenario (ZAR -49 035/ha) and in particular, the observed low efficiency active re-vegetation scenario (ZAR -101 581/ha) had the lowest net present values.

The general trend across the scenarios was that the Grassland biome has a higher net present value compared to the Fynbos biome, owing to the greater water and grazing benefits (Table 4.3). In the Fynbos biome the containment scenario (Table 4.3) had the highest net present value (ZAR -2 742) out of the treatment scenarios, whereas in the Grassland biome the containment scenario had a far lower net present value (ZAR -15 472) because of the higher foregone benefits.

The aggregate net present value of the treatment scenarios was ZAR - 250.2 million for low efficiency removal, ZAR - 11.7 million for high efficiency removal, ZAR 521.3 million for low efficiency active re-vegetation, ZAR 109.5 million for high efficiency active re-vegetation and ZAR - 66.9 million for the containment scenario.

Table 4.3 Net present value (ZAR = South African rands; 1 US$ = approximately 7.4 rands) over a 30 yr. period at a discount rate of 4%, for each Water Management Area within the Grassland and Fynbos biomes in 2011-equivalent ZAR.

Water management area	Low efficiency	High efficiency	Low efficiency	High efficiency	Containment
Breede	-57 277	-10 689	-130 917	-31 651	-2 578
Crocodile and Marico	-53 790	-7 202	-100 945	-25 772	-6 937
Fish to Tsitsikamma	-56 027	-9 440	-120 320	-29 558	-4 140
Gouritz	-57 080	-10 492	-129 617	-31 354	-2 825
Inkomati	-55 192	-8 604	-102 347	-27 174	-5 184
Limpopop	-54 750	-8 162	-101 904	-26 732	-5 737
Lower orange	-56 995	-10 407	-104 149	-28 977	-2 931
Middle Vaal	-52 866	-6 279	-100 021	-24 849	-8 091
Mvoti to Umzimkulu	-49 387	-2 800	-96 542	-21 370	-12 440
Mzimvubu to Keiskamma	-43 468	3 119	-90 623	-15 451	-19 839
Olifants	-44 276	2 312	-91 430	-16 258	-18 830
Olifants/Doorn	-58 243	-11 656	-131 884	-32 618	-1370
Thukela	-50 609	-4 021	-97 764	-22 591	-10 913
Upper Orange	-55 533	-8 945	-102 688	-27 515	-4 758
Upper Vaal	-14 619	31 968	-61 774	13 398	-55 900
Usutu to Mhlatuzu	-50 105	-3 517	-97 259	-22 087	-11 544
Grassland mean (total)	-46 962 (-186.4)	-374 (-94.9)	-94 116 (-375.0)	-18 944 (-74.4)	-15 472 (-63.6)
Fynbos mean (total)	-57 146 (-63.8)	-10 558 (-11.7)	-130 786 (-146.4)	-31 520 (-35.1)	-2 742 (-3.3)
Total mean (total)	-49 035 (-250.2)	-2 447 (-11.8)	-101 581 (521.3)	-21 504 (109.5)	-12 881 (-66.9)

DISCUSSION

The key findings of the study are as follows. Based on the assumptions, the low-efficiency removal and especially the low-efficiency active re-vegetation scenario was the least cost-effective and financially feasible. High-efficiency removal was the most cost-effective and financially feasible scenario followed by containment and high-efficiency active re-vegetation. In all scenarios, with the exception of high efficiency removal, the costs exceeded the financial benefits. In the remainder of this section, I discuss what the potential is for these treatments in light of current understanding of the biophysical, financial and budgetary constraints.

Biophysical constraints

An important question for WfW regarding the feasibility of high-efficiency removal is whether removal alone is sufficient for ecological restoration, or if active re-vegetation is also needed. Holmes et al. (2008) summarized an assessment of the recovery of plant invaded riparian areas treated by WfW. They concluded that in the majority of cases native plant recovery occurred spontaneously in densely invaded areas. It was stressed, however, that this was dependent on the diligent application of treatments during the initial and follow-up stages. Further research is required to test what effect the quality of the treatment has on the success of restoration.

In other areas of the world, assessments of active re-vegetation versus removal only treatments have shown mixed results. For example, clearing of *Tamarix* riparian invasions resulted in greater native species richness but had little impact on suppressing alien plant regrowth (Harms and Hiebert 2006; Bay and Sher 2008). On the other hand, Jäger and Kowarik (2010) found that removal of the invasive plant *Cinchona pubescens* resulted in the spontaneous recovery of native vegetation in the Galapagos.

With regard to the resistance of restored sites to re-invasion, drawing from community ecology theory, Funk et al. (2008) argue that "successful restoration efforts should select native species with traits similar to likely invaders and include a diversity of functional traits." In the Grassland and Fynbos biomes a possible reason why *A.mearnsii* is so successful is because it exploits the fact that the biomes are mostly treeless (Cowling and Richardson 1992). It therefore has no competition from other native fire-adapted trees. Future re-vegetation studies would benefit from testing community ecology theory. Related to this, it is important to consider that ecological restoration might not be feasible in some cases. For example, in sites that were degraded or transformed prior to invasion, it might be more realistic to adopt a novel ecosystem approach and not try to restore according to the historical composition of a site (Ewel and Putz 2004; Hobbs et al. 2009; Davis et al. 2011).

Financial constraints

The ability of landowners to pay for follow-up and maintenance is a critical constraint for the long-term control of invasive plants on private land (Urgenson et al. 2011). For example, in all the scenarios, the costs would outweigh the private financial benefits, i.e. grazing gain, even with a low discount rate of 4%. As it currently stands, private landowners do not gain the full public benefit of alien plant control, such as the downstream water flow benefits. Therefore, amongst other approaches further work is required to link water-beneficiaries with the land-users (Turpie et al. 2008). An innovative idea proposed by Blignaut et al. (2009) is to create energy from the biomass of removed woody alien plants thus further offsetting the costs. On the cost side, improving the quality and effectiveness of the treatments would also improve the financial feasibility of the treatments for private landowners. For example, as mentioned, poor quality treatments, such as those measured in the low-efficiency removal scenario, result in higher follow-up costs. WfW urgently needs to determine the true extent of the area where its current conventional removal treatments are ineffective and how much of this results from poor quality clearing or biophysical constraints described above.

Budgetary constraints

As is the case of health care or education, budgets for environmental management are limited; triage is therefore unavoidable (McDonald-Madden et al. 2008). Numerous studies have shown how failure to incorporate costs into the prioritization process will result in lower overall effectiveness (Murdoch et al. 2007; McCarthy et al. 2010). For example, in the case study, it would cost the entire annual 2010 WfW budget to treat the study area with the low-efficiency active re-vegetation removal scenario. If this area were to represent 2% of the entire *A. mearnsii* invasion in South Africa – as I assumed – the lost opportunity costs of not spending this money on treating less altered riparian areas or simply containing the current spread would be very large. WfW could determine the true extent of the area where *status quo* removal is ineffective and how much of this results from poor quality clearing or biophysical constraints described above. In addition to this, future research could determine how to lower the costs of active re-vegetation. This might be achieved by decreasing the planting density and propagating material in the field to eliminate the nursery and transport costs.

CHAPTER 5: IDENTIFYING THE CHALLENGES OF LINKING ECOLOGICAL RESTORATION AND POVERTY ALLIEVIATION WITH PUBLIC WORKS[4]

INTRODUCTION

It is important to understand how an organization's structure and design (i.e. government versus market based) shapes the effectiveness of its interventions (Sutherland et al. 2009). A substantial body of research in conservation and restoration has examined how to design and implement interventions but little research has focused the detail of these activities on the ground.

Public works are government job-creation programmes that use labour to build or restore public infrastructure, for example, roads, hospitals, and in some cases, ecological infrastructure such as degraded land. They have been used for centuries throughout the world, and today are supported by large donors such as the World Bank and used by many governments (Subbarao et al. 1997; Ninno et al. 2009). In the ecological restoration literature, they have been heralded as a possible win-win strategy for alleviating poverty whilst simultaneously restoring ecological infrastructure (Woodworth 2006; Koenig 2009). For ecological restoration, which has been criticized for detaching itself from developmental concerns (Aronson et al. 2006, 2010), public works provides an opportunity to address this shortcoming, particularly in the developing world.

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[4] This chapter is being prepared for *Restoration Ecology*.

Why are public works popular? Other than their win-win appeal described above, funders are attracted by the cash in-kind arrangement whereby the poor work for their income instead of a conventional unemployment grant (Lieuw-Kie-Song 2009). A second argument is that it can solve the difficult challenge of selecting and ensuring that only the poorest benefit. By setting the wage at or below the minimum wage only the poorest will volunteer (Lieuw-Kie-Song 2009). Thirdly, it has strong political appeal because unlike longer-term remedies that treat the cause of labour market failure – such as education, regulation and macro-economic policy adjustments – public works provides immediate relief and the impression that the government is taking direct action to reduce unemployment (McCord 2007). Furthermore, this could arguably help decrease social unrest over rising inequality and jobless growth.

A commonly cited example of a public works driven ecological restoration project is South Africa's alien plant control programme, 'Working for Water' (WfW) (van Wilgen et al. 1998, Hobbs 2004; Turpie et al. 2008). It forms part of the country's Expanded Public Works Programme (EPWP), which is the sole provider of aid for South Africa's enormous working-age unemployed population (Department of Public Works, 2009) (Figure 5.1). Established in 2004, the EPWP's ambitious millennium development goal was to halve unemployment by 2015 (McCord 2007).

Within the EPWP, WfW is its largest environmental programme and one of the main programmes to provide aid for South Africa's poor rural population, most of which is unemployed. Partly as a result of these goals and its large annual budget (approximately half-a-billion ZAR in 2011), WfW is lauded as the most ambitious alien plant control programme in the world (Keonig 2009). The programme's economic argument for clearing alien plants is based on its ability to restore ecosystem services such as surface water run-off and improve grazing potential (van Wilgen et al. 2008). Despite these ambitious goals, little is known about its effectiveness in reaching these goals (but see Chapter 2).

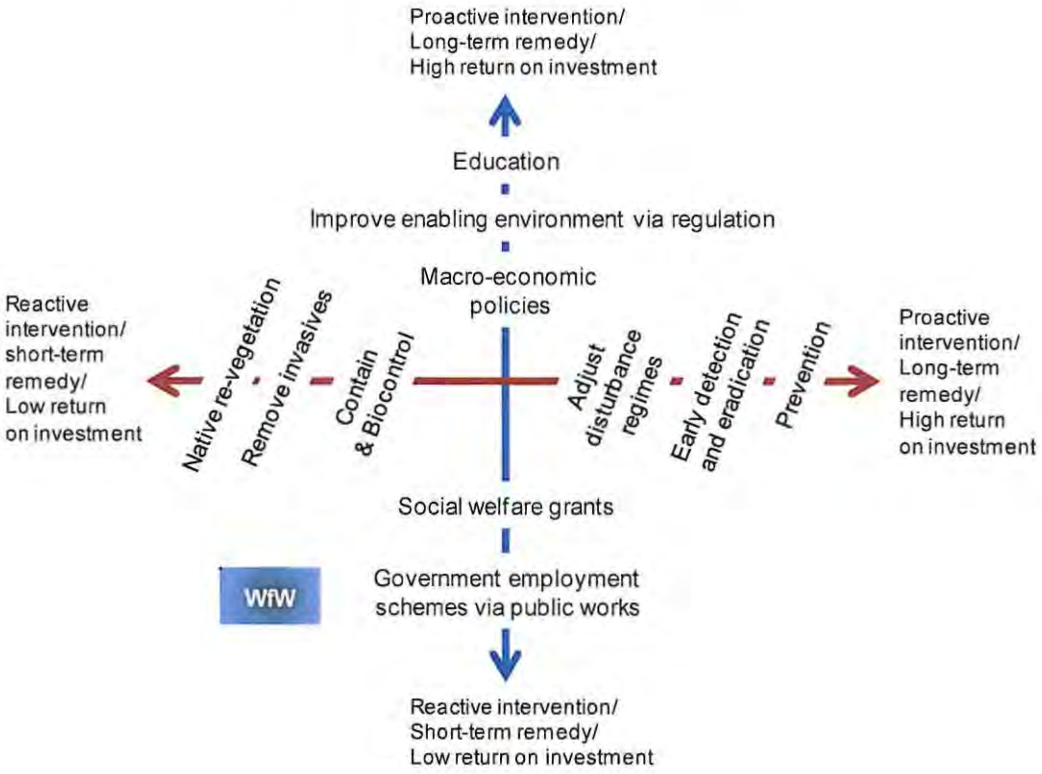

Figure 5.1 The y-axis of the diagram shows the intervention options available to the South African government in addressing poverty alleviation and unemployment. The x-axis shows intervention options for reducing the impact of invasive alien plants on biodiversity and ecosystem services. The interventions are scaled from reactive to proactive measures. Because the primary concern of the South African government is with alleviating poverty and unemployment the only overlap with invasive plant control objectives is in the reactive – labour intensive – interventions such as eradication.

A recent national-scale assessment by van Wilgen et al. (2012) showed that the WfW programme was not going to fulfil its goal of reducing the overall impact of plant invasions within a reasonable timeframe. They concluded that since its inception in 1995 - and despite an investment of 3.2 billion South African rands (ZAR) (1 US$ = approximately ZAR 7.4) – WfW had only treated a small fraction of the total alien plant cover, and that alien plant cover had actually increased in extent during the programme's operation, although arguably at a rate slower than if the WfW programme had not been operational.

In evaluating the broader effectiveness of the EPWP in halving unemployment by 2015, McCord (2007) found that the EPWP was only employing a small fraction of the unemployed population. Despite employing one million people in 2007, the EPWP focus on providing temporary or part-time employment results in only 200 000 full-time job equivalents – a small fraction of the 5 million unemployed people in South Africa. WfW mirrors this pattern: whilst annually employing 20 000 to 30 000 people (Marais and Wannenburgh 2008; Keonig 2009), it provides full-time employment equivalents for about 5 000 people.

Within this context, I sought to understand the drivers of the challenges facing WfW in achieving its goals, and to learn from them. I did this by interviewing WfW managers regarding the challenges they face in fulfilling the programme's goals. This is the first study of which I am aware that assesses and synthesizes the knowledge of managers against the literature on both the poverty alleviation and environmental outcomes of a public works project.

METHODS

Working for Water and study area background

WfW consists of approximately 300 projects operating in all of South Africa's nine provinces. My case study site, the western region of the Eastern Cape province, had two WfW implementing agents operating in the area, consisting of the Gamtoos Irrigation Board and South African National Parks (Sanparks). The irrigation board's sites are located on private land whereas Sanpark's sites are within protected areas (i.e., national parks).

In terms of organizational structure, the responsibility of the WfW national and provincial managers of WfW is to ensure that the work is correctly carried out by the implementing agents. The implementing agent staff comprise of project managers who report to their respective area (regional) managers. The work itself is carried out on a monthly contract basis by teams of workers. The project managers allocate contracts that specify an area of alien-invaded land that must be cleared within that month. Each contract is allocated to the team comprising a team leader (contractor) and 10-15 labourers, recruited from the large numbers of unemployed people in the surrounding area. Each project has, on average, five to seven operational clearing teams at any time. Employment for the workers is episodic and until recently they and the contractors were only allowed to rely on the programme for a maximum of two years before having to make way for other unemployed people.

The main invasive alien plant species targeted by WfW are shrubs and trees of Australian origin in the genera *Acacia* and *Eucalyptus*. All component species coppice after felling and fire as well as species of *Pinus* indigenous to the Mediterranean Basin and North and Central America. Of less significance are non-woody species such as *Lantana camara, Solanum mauritianum, Cestrum jamacaru* and *Chromolaena odorata* (Marais et al. 2004; Marais and Wannenburgh 2008).

The effective control of coppicing woody species requires felling, followed immediately by the careful application of herbicide to the cut stems, to kill the plant and thereby prevent coppicing. In the case of *Acacia* spp, clearing also stimulates the *en masse* recruitment of seedlings from a large and persistent soil-stored seed bank. Numerous and timely follow-up treatments are required to treat both seedlings and coppice re-growth with herbicide, and is compounded when previous treatments are of a poor quality. If the regrowth height exceeds approximately 1.8 m, herbicide is ineffective and plants must be re-felled, the latter being far more costly (Holmes et al. 2008). WfW's policy regarding clearing on private land is that landowners will contribute to part of the cost of clearing as well as agree to maintain sites free from re-invasion after WfW's have completed the first follow-up treatment.

The western area of the Eastern Cape is characterized by a semi-arid climate with unpredictable year-round rainfall. It supports predominantly thicket, fynbos and grassland vegetation (Mucina and Rutherford 2004). Invasive alien plants pose a threat to the high levels of biodiversity and scarce water resources (van Wilgen et al. 2008). The province is the second poorest in South Africa, and the public works programmes like WfW are the primary source of government aid for the millions of working-age unemployed (Eastern Cape Provincial Treasury 2011).

Manager interviews

In total I interviewed 23 managers consisting of 10 project level managers, three area managers, one provincial manager, three WfW consultants and six national managers (based in the WfW national head office). I interviewed approximately 85% of the managers in the western region of the Eastern Cape. I restricted the selection of interviewees in the national office to those who were directly involved in the planning of operations and not administrators who represent the bulk of the national office staff members.

I conducted the interviews face-to-face, over the telephone and via email depending on the availability of managers. The questions were open-ended and reflected the types of challenges faced by the managers in fulfilling WfW's environmental and poverty alleviation goals. More specifically, I asked them what the reasons were for the manifestation of the challenge, resultant impacts, and possible solutions for overcoming the challenges.

To identify emerging themes from the open-ended responses, I used thematic coding based on the grounded theory approach (Creswell 2009; Birks 2010). To rank the themes, I recorded the number of managers that cited each theme. I then grouped these emerging themes into five broad categories. I also divided the managers into a regional and national group. The national managers consisted of the six national WfW managers and the one provincial manager. I classified the remainder of the managers as regional.

RESULTS

The most frequently cited challenges expressed by interviewees related to the poor capacity and quality of managers and teams, followed by challenges relating to planning and coordination (Table 5.1).

Table 5.1 The percentage of the managers who listed challenges falling within each of the five broad categories. Themes within each category are shown in italics.

	Regional managers (n=16)	National managers (n = 7)	Total managers (n = 23)
Capacity and quality of managers and teams *Capacity and quality of the managers and teams to carry out their responsibilities effectively and efficiently*	81	43	70
Planning and coordination *Adaptability and flexibility of operations; planning with the focus being on short-term job creation and the other objectives not clearly defined; political pressure to operate in some low-priority areas; coordination challenges between different government departments*	50	71	57
Landowner compliance *Enforcement and incentive for landowners to maintain sites treated on their land; landowner type and experience*	44	43	39
Poverty alleviation effectiveness *Selecting the poorest people to work in the programme; adequate training so that they can find employment; long-term difference the program makes to their livelihood; WfW only employ a very small fraction of the total unemployed*	44	29	39
Monitoring and evaluation *Related to the monitoring and evaluation of data management, alien plants, implementation performance, landowner compliance and poverty alleviation outcomes*	13	57	26

Capacity and quality of managers and teams

The most commonly cited reasons for the poor capacity and quality of managers related to the difficulty of attracting and maintaining managers with suitable education, skills and experience. In addition, the low management to worker ratio, and the inflexibility of operations – stemming from rigid protocols and recruitment procedures – were also cited as reasons for poor management capacity and quality. With specific reference to the teams, the managers highlighted their lack of motivation and discipline resulting from inadequate performance incentives, as well as their lack of ethics related to work and environmental concerns. The managers also cited the challenge of working with unskilled workers who had little experience and knowledge of alien plant control. This was due to WfW being a public works project, and so must employ the poorest and least skilled workers. The impacts of the poor effectiveness of both management and teams was wasted resources, fewer environmental benefits stemming from less effective reduction of alien plant cover, the persistence of workers' poverty after they were released from the programme, and manager burnout. Potential solutions included increasing the accountability of operational staff through effective monitoring and evaluation, as well as directly linking worker performance to incentives. All levels of management were highlighted as important, with specific emphasis given to project level managers. More effective training of staff was also cited, coupled with improved screening when recruiting staff. For the teams this involved more emphasis on selecting well-capacitated contractors. The majority of the regional managers cited challenges relating to this category, whereas only a minority of the national managers emphasised improvements for selecting well-capacitated contractors.

Planning and coordination

The cited challenges related primarily to the inability of project managers to be flexible and adapt their plans to changing circumstances. The managers also cited the difficulty of planning arising from a focus on short-term job creation and poorly defined objectives relating to objectives other than the imperative to create jobs. One manager cited political pressure to operate in areas that were not priorities for employment or alien control. Managers also cited poor coordination with other state departments (lack of co-governance). The primary reason cited for the general lack of flexibility was attributed to bureaucratic impediments resulting from government's rigid protocols. One manager believed this inflexibility stemmed from WfW's hierarchical and top-heavy structure. The overall impacts were wasted resources, and sub-optimal environmental and social outcomes. The managers' proposed solutions to these challenges were for better planning and coordination, and improved monitoring and evaluation. Three managers believed that the EPWP's exclusive goal of employing as many people as possible, regardless of the costs (i.e., lower quality work and limited long-term livelihood improvement), needed to be re-examined.

Landowner compliance

The main challenge for ensuring the long-term eradication of invasive alien plants on sites treated by WfW on private land was a lack of incentives and enforcement for landowners to conduct on-going follow-up treatment of sites (as required by law) so that they were not re-invaded. To a lesser degree, general education and awareness, as well as engagement with landowners, were also cited as challenges. The main reasons cited for the lack of enforcement and incentives were legislative failings, and the capacity and willingness of other state departments – most notably the Department of Agriculture, Forestry and Fisheries (DAFF) – to implement enforcement or provide financial incentives for landowners to remove alien plant re-growth. Low landowner compliance has led to WfW resources and interventions being squandered. The recommended solutions were for legislative enforcement to take place and for sufficient capacity to be allocated to this task. Managers also cited improved engagement and use of market incentives for the landowners.

Poverty alleviation effectiveness

The two main themes relating to this issue were WfW's imperative to select the poorest and least skilled workers and the inadequacy of training. A further issue linked to the latter challenge was ensuring that the teams received training that would assist them in finding employment beyond the WfW programme. One project manager mentioned that WfW was only employing a very small fraction of unemployed people in their region. The main reason cited for poor targeting resulted from selection committees – largely comprised of local community leaders – being influenced by nepotism and political favouritism. With regard to the inadequate quality of training, managers blamed this on the ineffectiveness of the Department of Labour – the chief service provider for worker skills training, as well as the low education level of many of the workers. The consequence of a compromised selection process meant that the most poverty stricken people often did not benefit from the programme. In addition, four managers cited that the programme made little difference to the long-term livelihood of workers, and one of the managers mentioned that the programme could actually worsen their long-term livelihood prospects by diverting them from finding more sustainable long-term income flows. The suggested solutions were for better screening for poverty status and improved skills training by auditing the service providers.

Monitoring and evaluation

The managers cited as key challenges the inadequate level of monitoring and evaluation of treatments, including the recording of alien plant baselines, enforcing landowner compliance, and the capacity and motivation to conduct all of the above. The main reasons cited for this had to do with capacity and budget constraints. One of the managers also mentioned the exclusive focus of the EPWP on measuring person day inputs and the quantity of beneficiaries, meant that WfW had little incentive to monitor anything else. The impacts were wasted resources as well as knock-on effects such as poor quality treatments and incompetent management, owing partly to poor accountability. Some of the cited solutions included ensuring managers provided assessment reports were held accountable for achieving outcomes, and increased monitoring and evaluation. One suggestion was for implementing agents to have a performance incentive linked to the monitoring and evaluation of on-the-ground effectiveness. This specific challenge was only cited by two of the consultant managers and none the permanent managers. Overall, a far greater percentage of national level managers cited challenges relating to monitoring and evaluation compared to regional managers.

DISCUSSION

McCord (2008) argues that one of the core reasons for the challenges faced by South Africa's EPWP results from it being geared toward relieving short-term poverty and unemployment through maximizing person days of employment and the number of beneficiaries. Economic theory suggests that this approach can be effective in reviving an economy during a downturn by boosting confidence in the economy and providing temporary employment. In terms of skills transfer it can be effective when the training fills skills gaps in the formal economy. This approach, however, is arguably not well suited to the South African context with its long-term unemployment and poor skills transfer to workers is chronic problems in an already saturated in the formal economy (Kingdon and Knight 2004).

Hope (2006) argued that the skills transfers associated with brief bouts of employment made little difference to WfW worker's long-term competitiveness and marketability. Furthermore, the episodic nature of the employment makes it difficult for workers to improve their livelihood strategies, and in some cases can damage their existing strategies (Aliber 2002; Hope 2006; Buch and Dixon 2009). The programme has also been criticized for not effectively selecting the poorest and neediest workers (Hope 2006), contradicting the assumption that public works automatically solve the challenge of employing the poorest of the poor to work in the programmes (Subbarao 1997). These concerns were echoed by the majority of interviewees in my survey.

A further limitation of the focus on short-term employment maximization cited by managers was that it impacted on the capacity and competence of the managers and teams to achieve objectives and efficiently conduct their duties. Managing watershed services effectively is vitally important for securing South Africa's scarce water resources (Blignaut and van Heerden 2009) and hence the growth of its economy. Despite the importance of this, indications are that WfW might not be cost-effectively reducing alien plant cover (van Wilgen et al. 2012; Chapter 2); consequently, it is failing to provide these services. For example, Chapter 2 showed that only a small fraction of WfW's total costs were being spent on wages. Even when wages are considered a social benefit WfW still would not be cost-effective. The above is exacerbated by WfW's (and the broader EPWP) inability to measure the impacts of their interventions, for example, the change in alien plant cover and reduction in poverty (Levendal et al. 2009). This makes it difficult for the programme to learn. Tellingly, only a minority of the managers cited this as a challenge.

How can WfW improve its effectiveness in simultaneously striving to restore ecosystems and alleviate poverty? Firstly, clear objectives need to be set and then these need to be monitored and evaluated in an adaptive management framework (Levendal 2009; van Wilgen et al. 2012). Secondly, focusing on selecting, training and maintaining workers in the long-term instead of short-term employment could improve the effectiveness of the invasive alien plant eradication. McCord (2007) recommends focusing on long-term sustained employment (such as India's Employment Guarantee public works programme), providing higher wages, and adopting independent measures to select workers. This would address one of the most commonly cited challenges faced by the managers namely, the capacity and competence of the teams. Thirdly, as cited the managers, WfW's inability to incentivize or enforce landowners to maintain their land after WfW have treated it results in wasted expenditure. EDA (1999) argued that WfW, in contrast to community-based land management, does not empower landowners to take ownership of controlling invasive alien plants. Fourthly, de Lange and van Wilgen (2010) argued that WfW should focus on more cost-effective bio-control treatments despite these being less labour intensive than the conventional manual clearing implemented by WfW. In addition, cost-effectiveness could be improved by targeting incipient invasions (Higgens et al. 2000). Fifthly, greater attention should be given to understanding the negative impact that clearing alien plants has on the poor's livelihood, by depriving them of fuelwood and building timber (Shackleton et al. 2006).

In summary, managers identified significant challenges, but importantly all were regarded as surmountable. The key lesson is that public works program objectives and structure should be designed for specific unemployment problems, which can in turn improve the efficiency and effectiveness of the work. Furthermore, it is vital that WfW measure the effectiveness of their interventions in an adaptive management framework. Public works have the potential to play a vital role in improving access to ecological goods and services, addressing labour market failure, and easing the plight of some of the unemployed.

CHAPTER 6: CONCLUSION

There is a shortage of evidence-based knowledge on the cost-effectiveness of restoring plant invaded landscapes. Furthermore, few studies conduct or monitor treatments over temporal and spatial scales relevant to operational contexts. Most cost calculations are based on estimates from experimental trials and not measurements of costs in operational contexts. With regard to the actual use of evidence-based knowledge by managers, little is known about what these findings add to managers' existing experience-based knowledge and whether they are willing to change their beliefs after being exposed to it. Finally, little is known about the challenges and set-backs involved in linking poverty alleviation with ecological restoration within the public works model.

To fill these gaps, using South Africa's WfW programme as a case study, the objectives of the thesis were as follows: (1) Assess the cost-effectiveness of reducing alien plant cover over time and the factors that underpin its cost-effective control (2) Assess what additional knowledge is gained by an evidence-based study and whether managers are willing to change their beliefs after being exposed to it (3) Assess the costs and benefits of restoration scenarios involving containment, removal and active re-vegetation of riparian plant invaded areas (4) Assess the challenges faced by managers in implementing ecological restoration and poverty alleviation within a public works model.

In the remainder of this chapter, for each objective, I briefly summarize the key findings and how successful I was in filling the gaps identified in the introduction. I also discuss the gaps that remain and what future research could examine. In the final section I relate the challenges faced by WfW to organizational theories and discuss specific policy ideas for WfW.

Objective 1 *Assess the cost-effectiveness of reducing alien plant cover over time and the factors that affect cost-effectiveness*

In chapter 2, I evaluated the cost-effectiveness of reducing alien plant cover in two of WfW's catchment river clearing projects over a seven year period. I based this on a before-and-after evaluation by comparing a snapshot of post-treatment cover with pre-treatment cover across all 740 sites within the two catchment areas. I also used regression analysis to estimate the effect of predictor variables on the cost-effectiveness of invasive alien plant clearing.

My study identified several problems that, if considered together, indicate that current control efforts are insufficient to prevent the on-going spread of a serious invasive species, despite significant spending. At best, the rate of spread of invasive species at a catchment scale is only slowed down, not stopped, and in many places spread continues despite clearing efforts. Even if spread could be stopped, at the current rates of clearing it would still take 54 and 695 years to clear the Krom and Kouga catchments, respectively. In addition to this, there seems to be little or no effort on the part of private landowners to maintain cleared land in a cleared state, so the cleared land is simply re-invaded. In comparison to the highest equivalent estimate made in other studies I found - by dividing the total costs by the change in invasive alien plant cover - that it cost 2.4 times more (1.5 times for the Krom, and 8.6 times for the Kouga project) to clear invaded condensed ha of land.

I discussed four possible interventions that may help to improve this situation in the catchments. First, resources need to be allocated to a project so that it could at the very least contain the spread of the invasive plant population. For example in the case of the Kouga project – with its large invasive plant population – even if control efforts had been efficient the amount of resources allocated would likely still be insufficient to control the spread of alien plants, let alone decrease the extent of the population. The second would be to invest in improved biological control solutions and monitor its cost-effectiveness. Currently there are few records of where biological agents are released and insufficient monitoring of the effect they are having in operational contexts (A. Wannenburgh, personal comm. 2011).

The third intervention would be to improve levels of professionalism especially of WfW managers. Monitoring the cost-effectiveness of projects and holding managers accountable for their performance is an obvious step that could be taken. The final discussed intervention was how to find a more effective way to deal with areas that have been cleared on private land. I will discuss the latter two interventions in greater detail in the final section.

The findings of my study highlight the importance of monitoring and understanding the effectiveness and efficiency of ecological interventions in real-world operational contexts. My assessment is of course not representative of all WfW's operations and generalizations cannot be drawn about the cost-effectiveness of WfW as a whole. However, the lower than predicted cost-effectiveness with regard to both the delivery of its environmental and social objectives highlights the importance of WfW extending the evaluation carried out in this study to all its projects. Monitoring and evaluating will enable Working for Water to learn and adapt its operations to make the best possible use of its budget.

A limitation of my study was that the assessment was based on a before-and-after evaluation without a control. I therefore could not isolate the causal effect of different factors on the cost-effectiveness of control. I also could not measure the effect of potentially important variables such as management quality, landowner cooperation and the type of treatment used. Future research using experimental controls would be able to shed light on this. For example with regard to the quality of clearing, high quality clearing could take place alongside standard clearing. Where this is not possible the use of econometric matching techniques could be used to make counterfactual inferences (e.g., Ferraro et al. 2007).

Objective 2 *Assess what additional knowledge is gained by an evidence-based study and whether the managers are willing to change their beliefs after being exposed to the result.*

In chapter 3, I tested managers' beliefs before and after being shown findings from an evidence-based study. The questions revolved around the effectiveness of WfW in reducing invasive alien plant cover in two large catchment projects over a seven year period, as well as the managers' forecasts of WfW's effectiveness of reducing invasive alien plant cover in the future, and the factors that underpin its effectiveness. I also assessed the financial cost of implementing the evidence-based assessment.

I found that in comparison to the evidence-based findings, the managers underestimated the ineffectiveness of operations in the one catchment and overestimated the ineffectiveness of the other, in reducing invasive alien plant cover. All the managers whose estimates differed from the evidence-based findings were willing to change their beliefs. Surprisingly, however, when it came to forecasting WfW's future effectiveness in the catchments, all the managers, with the exception of one project manager, were unwilling to reduce their optimistic estimates of the time required to remove invasive alien plants from the two catchments. With regard to the drivers of effectiveness, the managers ranked their performance as the most important criterion whereas the data model emphasized variables related to site suitability for alien plant growth. Finally, I showed that it would only cost between 0.33% and 1.67% of the two projects' annual budgets to assess all sites, depending on the frequency of the monitoring.

A key challenge facing restoration and conservation is the gap between research and practice (Knight et al. 2008; Esler et al. 2010). Most of the focus has been on linking scientific research with operational contexts (Knight et al. 2006). Little attention has been given to the actual difference scientific findings make to managers' experience-based knowledge and whether they are willing to change their beliefs after being exposed to them. Further research is required to test the hypothesis that when managers have strong incentives to be biased, evidence will have less impact on the beliefs. A shortcoming of my research was that I only measured attitudinal belief changes, not actual behavioral changes. Future research would benefit from testing how evidence changes managers' attitudinal and behavioral changes. In addition, research would also benefit from investigating rival explanations for the managers' beliefs such as what impact the communicator of the evidence has on changes of belief and whether the evidence is actually accurate.

Experience-based decision making has the potential to be very useful in many situations, especially when gathering evidence based knowledge is costly (Roux et al. 2004; Gigerenzer and Brighton 2009). I found that the managers' prior estimates, especially the managers of the catchment projects, were not far off the evidence-based measurements. However when the managers have strong incentives to be biased, i.e. when forecasting their future effectiveness, it makes sense to formalize this process and use models to predict these types of estimates based on empirical evidence. In addition it would help to assist managers in overcoming the biases to which they may be prone. The relatively low estimated cost of the monitoring the sites strengthens the case for WfW to monitor the effectiveness of its operations.

As in the case of chapter 2, the sample of my study is certainly not large enough to draw general conclusions about WfW managers let alone conservation managers as a whole. However, it raises an important issue that has not been given any attention in conservation and yet is vitally important to the success of restoration and conservation.

Objective 3 *Assess the costs and benefits of restoration scenarios involving containment, removal and active re-vegetation for riparian plant invaded areas*

In chapter 4, I evaluated the potential costs and financial benefits of three restoration scenarios for riparian areas in the Grassland and Fynbos biomes invaded by *A. measrnsii*: namely removal, removal followed by active re-vegetation and containment. For each scenario, I included a high and low-efficiency sub-scenario. The high-efficiency scenario was based on cost estimates if operations were carried out efficiently and effectively, whereas the low-efficiency estimates were based on actual measurements of cost-effectiveness in WfW. This study is important because few studies have compared the costs and financial benefits of active re-vegetation of plant invaded landscapes (Kettenring and Adams 2011). In addition, knowing the relative spatial variability of costs and benefits is important for targeting areas so that the scarce conservation and restoration funds can be put to their best possible use (Naidoo et al. 2006).

I found that, based on my assumptions, the low-efficiency removal and especially the low-efficiency active re-vegetation scenarios were the least cost-effective and financially feasible. High-efficiency removal was the most cost-effective and financially feasible scenario followed by containment and high-efficiency active re-vegetation. In all scenarios, with the exception of containment and high-efficiency removal, the costs exceeded the grazing and water financial benefits. It, however, is important to emphasize that I did not measure the total economic value of for example biodiversity.

Although this study should only be treated as a scenario analysis, based on the high cost of active re-vegetation, I recommended that WfW should firstly focus on isolating the effect that the quality and type of removal treatment has on native plant recovery. In addition - with regard to active re-vegetation a better understanding is required into whether restoration using native species makes a site more resilient to re-invasion, and if so what plant composition is needed.

Objective 4 *Assess the challenges faced by managers in implementing ecological restoration and poverty alleviation within a public works model*

In chapter 5, I attempted to understand the challenges and constraints faced by WfW managers in fulfilling the programme's environmental and poverty alleviation objectives. I found that the most frequently mentioned challenges expressed by the interviewees related to the capacity and quality of managers and teams. This was followed by challenges relating to planning and coordination which in turn could be related to the difficulty of being flexible and adaptive in the face of rigid protocols and operating procedures.

Public works have been posited as a win-win for ecological restoration and poverty relief. Yet little is known about the challenges of such programs. This is arguably the first study that synthesizes the knowledge of managers with the literature on both the poverty alleviation and environmental outcomes of a public works project.

What emerged from this chapter was that many of Working for Water's challenges are symptoms of the higher level policy decisions of how the public works should operate in South Africa. With the primary emphasis placed on maximizing short term employment, all other deliverables arguably suffer, such as the efficiency and effectiveness of treatments and long-term difference to human livelihoods. Therefore any attempt to improve WfW effectiveness and efficiency will arguably have to address the broader EPWP policy strategy. That said I believe that a win-win is still possible. Improving the quality and duration of the employment is likely to improve the quality of the work.

What this study also highlights is that WfW is first and foremost a public works program. This is the sole reason why it receives such a large budget. Thus, all effort should be placed on making the most of this model. This study attempted to do this by discussing some alternatives from the public works literature. The lessons learnt could be of use to other governments considering the use of ecological restoration public works programmes. Furthermore, this chapter highlighted how the organization's design is crucial to understanding how ecological interventions are implemented. A potentially fruitful avenue of research would be to compare WfW's public works organizational model to other organizational designs.

THEORETICAL SYNTHESIS AND POLICY SUGGESTIONS

Information – particularly who has it and who doesn't – is crucial to the efficient functioning of an organization. In this closing section I examine how the distribution of information within WfW and between itself and the South African public might affect the efficiency of operations. I examine this through the lens of agency theory and the organizational learning literature. I argue that a solution to WfW's challenges will need to draw from, and find a balance between, these two paradigms and what they prescribe.

The micro-economic perspective: agency theory

Agency theory is concerned with the contractual performance between a principal who hires an agent to perform a task on their behalf (Figure 6.1). The theory predicts that contractual performance problems occur when the principal has imperfect information about the actions (or effort) of the agent (Eisenhardt 1989; Milgrom and Roberts 1992). This can occur when acquiring the information is costly or difficult to measure. If the agent will receive the same net benefit regardless of their actions then there will be no reason for them to give their best effort. In other words they are not exposed to the same risks as the principle. The agent will therefore not be motivated to act in the interests of the principle by maximizing their effort. An important assumption of the theory is that humans will always try to maximize their self-interests. They will not act out of loyalty to the principle or harbor any other altruistic motives. Whilst this assumption can be useful I will argue in the next section that taken too far this assumption could potentially erode the values of an organization and result in less cooperation and information sharing – a key focus of the organizational learning literature.

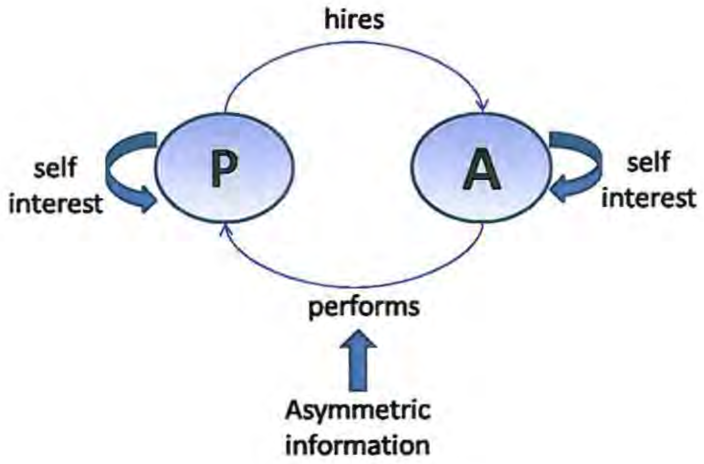

Figure 6.1 This figure shows an agency theory perspective of contractual agreements between a principal (P) and an agent (A).

How relevant is agency theory to the WfW context? I briefly discuss four areas where it might be of relevance: (1) between WfW and the South African public; (2) between WfW national office and its implementing agents; (3) between the implementing agents and the teams that they contract to work and (4) between WfW and the private landowners.

(1) The South African public's expectation of WfW is that they will maximize the production of jobs and the control of invasive plants. They however have little information about the actions of WfW, i.e. how efficiently and effectively they are fulfilling their objectives. This is compounded by two aspects. Firstly, it is difficult for the public to measure invasive plant control effectiveness. Unlike a school building or national highway it is arguably more difficult for the public to monitor the provision of invasive plant control. Secondly, because the individual public member would only benefit marginally from WfW's actions they have little incentive to monitor its effectiveness. The cost of doing so would probably offset any personal gain they would receive. Agency theory would assume that if WfW does not gain or lose from efficient production then they will have no reason to maximize their effort. That said it would be in WfW's interests to provide the public with

information about its actions so that it can lobby for more public funds. Borcherding (1977) argued that bureaucrats, in the absence of a profit motive, attempt to maximize their budgets because it increases their salaries, power and prestige amongst other benefits. If one assumes this, then they will only want to report on indicators that show the organization in a favorable light. One could argue that this is why WfW (and the broader EPWP) report on indicators such as "employment opportunities" or "hectares of alien plants treated" and not on more meaningful indicators as discussed in chapter 2 and 5. Furthermore one could argue that the cost of WfW monitoring this information (as estimated in chapter 3) is negligible and is therefore unlikely to be the reason for WfW not monitoring itself.

(2) Following on from the above point, the next potential application of agency theory lies between WfW's national office and its implementing agents. As described in the introduction, WfW consists of a national office that allocates funds to implementing agents who do all the operational work. WfW national office is therefore the principal who hires the implementing agent to do the work on their behalf. The problem is that because the national office does not monitor the effectiveness of treatments there is little incentive for the implementing agents to work efficiently – they do not bear the risk of failure. In the past two years WfW have introduced an incentive system for the implementing agent managers but it is based on indicators that are arguably not reflective of actual performance for example days of employment provided and hectares of land treated (broken into initial and follow-up treatments). As shown in chapter 2 and 5 these indicators might not be indicative of actual performance.

(3) Another application of agency theory lies between the implementing agent and the contractors who do the actual work. As mentioned in chapter 2 the contractors and their team are allocated a treatment site that they have to clear within a month. They are then paid after completion of the contract. It is therefore based on a piece-rate incentive scheme. The teams thus want to complete the contract as quickly as possible and move on to their next contract. They will not lose anything if the work is carried out inefficiently. The further problem is that the project managers have little incentive to monitor the quality and effectiveness of the treatments. As mentioned above, they are rewarded based on how many

person days of employment they can provide and how many hectares they can treat. They therefore are rationally ignorant to the effectiveness of the treatments.

(4) The principal-agent problem could also apply to WfW's contractual agreements with private landowners. If one assumes that the private landowners overriding self-interest is to maximize profit then they will not undergo follow-up treatments unless the cost of doing so is offset by the benefit. If the treatments are not carried out effectively by WfW then the landowner's follow-up costs increase due to higher coppicing rates of invasive plants. In addition, because the private benefits are relatively small (grazing value) compared to the social benefits (water value) (see chapter 4); the landowners have little motivation to do follow-ups. This is compounded by the fact that WfW does not monitor the contract to see that it is honored by the landowner. A further problem is that the control of invasive plants as argued by Perrings et al. (2002) is a weakest-link public good. Thus the long-term effectiveness of a WfW project is only as good as its least motivated landowner to carry out follow-up treatments.

The agency theory solution: information transparency and risk sharing

The key to improving contractual performance would be to improve information transparency. In micro-economic parlance: this would mean decreasing the information asymmetry from the agent to the principle. However, it will be impractical and too costly to monitor all the actions of the respective agents. Information-efficient proxies for monitoring effectiveness and efficiency will need to be used. As shown in chapter 2 monitoring the post-treatment invasive plant cover of sites over time and how much is spent on the sites would be an example of a good indicator to measure. Incentives could then be established that better align the interests of the respective principle-agent relationships. Thus the risk (or cost) of inefficiencies would be more evenly spread between the two parties. For example, in the case of WfW and the South African public, the public could insist that WfW maximize its objectives and hire an independent auditor to check that this is carried out to their satisfaction. It could then create incentives to motivate WfW to act in their interests. WfW in turn could use the same approach to motivate its implementing agents to act in the public's interest.

The same rationale could apply between WfW and the landowners. It could increase monitoring of contracts, adjust the subsidy it offers the landowners based on the private benefits that they will gain, and create incentives for the landowners to maintain the sites in the future. For example, a performance payment five years after the treatment has taken place. In addition WfW could create markets for invasive plant control by linking the beneficiaries (the water users) with the producers of the service (the landowners) (e.g., Blignaut et al. 2007, 2008 and Turpie et al. 2008). Markets have the potential to be more efficient as the buyers of the service will have more of an interest in ensuring that the sellers perform in their interests. It will also be easier for them to monitor if the producer is delivering the service efficiently. The producer, the landowners, will stand to gain more from providing the service efficiently. Instead of receiving a subsidy as is the current situation they could stand to gain a regular flow of payments. They will therefore be more motivated to ensure that the work is carried out efficiently. In this model WfW would focus on treating areas where the potential for markets do not exist, i.e. where the water benefits are low.

The organizational learning perspective: is it compatible with agency theory?

One argument for the success of the human species has been its ability to share information via social learning – this has allowed it to be flexible and quickly adapt to situations (Pagel 2012). Creating learning organizations where information is freely available is a vital process in adaptive management (Cowling et al. 2008; Grantham et al. 2011). As mentioned by Argyris (1999), a learning organization requires: "co-operation between individuals and groups, free and reliable communication, and a culture of trust." Therefore values such as trust, honesty and loyalty are vital for the success of an organization (Roberts 2007). However, sharing information is not always in the immediate self-interest of individuals or divisions of an organization competing against one another. Thus the agency theory assumption that people only maximize their self-interests would seem to be at odds with the objectives of the learning organization literature.

The problem of relying too heavily on performance incentives and risk sharing as proposed by agency theory is that they will always be room for agents to cheat and harm the interests of the agent. Especially in the context of invasive plant control, it will be very difficult to find a perfect proxy for effectiveness and hold agents completely accountable. They will always be a need for the agents to act in good faith even although it might not be in their immediate interest. Therefore organizational values such as trust, loyalty and honesty are critical to the success of an organization (e.g. see Robertson 2007's discussion of the role of values in the success of Japanese manufacturing corporations). For example some of the managers I have met in the WfW organization are certainly not driven solely by self-interest. They are motivated by the belief that they are making a difference, restoring the environment and/or alleviating poverty via public service. Therefore the danger of assuming that people only maximize their self-interests is that it could become a self-fulfilling prophecy, potentially eroding the values of an organization. That said it would be naïve to assume that people will not attempt, at least partly, to maximize their self-interests. Therefore it is important to find a balance between creating incentives that appeal to agent's self-interests and creating an organizational culture that fosters cooperation and learning.

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APPENDIX TO CHAPTER 4

Table A.1 Treatment timing and costs (ZAR) for high-efficiency removal (the low-efficiency removal and containment scenarios are explained in the methods section).

Year	Type	Cost (ZAR)
0	Initial removal	8 701
1	Follow-up hand pull 100% cover, over 2 years	764
2		764
3	Follow-up hand pull 75% cover, over 2 years	563
4		563
5	Follow-up hand pull 50% cover, over 2 years	241
6		241
7	Follow-up hand pull 25% cover, over 2 years	131
8		131
9	Follow-up hand pull 10% cover, over 2 years	60
10		60
11	Lopper young growth, 2% cover, every 2 years	56
12		56
13		56
14		56
15		56
16		56
17		56
18		56
19		56
20		56
21	Lopper young growth, 0.5% cover, every 2 years	14
22		14
23		14
24		14
25		14
26		14
27		14
28		14
29		14
	Total cost	12 907
	Total present cost (4% discount rate)	12 145

Table A.2 Treatment details for active restoration (the low-efficiency and containment costs are explained in the text).

	Fynbos			Grassland		
Year	Type	High-efficiency	Low efficiency	Type	High-efficiency	Low efficiency
0	Initial removal	8 701	8 701	Initial removal	8 701	8 701
1	Planting 1 stem per m^2	18 819	96 998	Planting 1 stem per m^2	22 358	100 537
2	Follow-up planting (1 plant per 3 m^2)	6 273	32 333	Hand-pull 25%, over 2 years	130	130
3	Hand-pull 25%	259	259		130	130
4	Hand-pull 10%, over 2 years	62	62	Hand-pull 10%, over 2 years	62	62
5		62	62		62	62
6	Lopper young growth, 0.5% cover every 2 years	14	14	Lopper young growth, 0.5% cover every 2 years	14	14
7		14	14		14	14
8		14	14		14	14
9		14	14		14	14
10		14	14		14	14
11		14	14		14	14
12		14	14		14	14
13		14	14		14	14
14		14	14		14	14
15		14	14		14	14
16		14	14		14	14
17		14	14		14	14
18		14	14		14	14
19		14	14		14	14
20		14	14		14	14
21		14	14		14	14
22		14	14		14	14
23		14	14		14	14
24		14	14		14	14
25		14	14		14	14
26		14	14		14	14
27		14	14		14	14
28		14	14		14	14
29		14	14		14	14
	Total cost	34 514	138 753	Total cost	31 780	109 959
	Total present cost (4% discount rate)	33 107	132 373	Total present cost (4% discount rate)	30 715	105 887

Table A.3 Water tariff price (ZAR = South African rands; 1 US$ = approximately 7.4 rands) per cubic meter of water per Water Management Area in 2011-equivalent ZAR.

Water management area	Price
Breede	0.03
Crocodile	0.09
Fish to Tsitsikamma	0.07
Gouritz	0.05
Inkomati	0.07
Limpopo	0.09
Lower orange	0.05
Middle Vaal	0.14
Mvoti	0.2
Mzimvubu	0.33
Olifants	0.34
Olifants/Doorn	0.01
Thukela	0.16
Upper Orange	0.06
Upper Vaal	1.04
Usutu to Mhlathuze	0.18
Mean	0.18

Table A.4 Cover represented in condensed hectares of *Acacia mearnsii* per water management areas values.

Water management area	Fynbos	Grassland	Sub-total	% Total
Breede	1 436.2		1 436.2	7.5
Crocodile		804.2	804.2	4.2
Fish to Tsitsikamma	1 081.4	247.2	1 328.6	6.9
Gouritz	1 620.4	0.1	1 620.5	8.5
Inkomati		696.5	696.5	3.6
Limpopo		31.0	31.0	0.2
Lower orange		3.6	3.6	0.0
Middle Vaal		69.9	69.9	0.4
Mvoti		2 140.1	2 140.1	11.2
Mzimvubu		6,209.8	6 209.8	32.4
Olifants		1 331.0	1 331.0	6.9
Olifants/Doorn	55.9		55.9	0.3
Thukela		945.9	945.9	4.9
Upper Orange		1 090.3	1 090.3	5.7
Upper Vaal		395.3	395.3	2.1
Usutu to Mhlathuze		1 006.4	1 006.4	5.3
Total	4 193.9	14 971.3	19 165.2	100.0