Biological Invasions **3:** 167–178, 2001.
© 2002 *Kluwer Academic Publishers. Printed in the Netherlands.*

Conflicts of interest in environmental management: estimating the costs and benefits of a tree invasion

M.P. de Wit[1], D.J. Crookes[1] & B.W. van Wilgen[2,*]
[1]*CSIR Division of Water, Environment and Forestry Technology, PO Box 395, Pretoria 0001, South Africa;*
[2]*CSIR Division of Water, Environment and Forestry Technology, PO Box 320, Stellenbosch 7599, South Africa;*
[*]*Author for correspondence (e-mail: bvwilgen@csir.co.za; fax: +27-21-8882693)*

Received 20 July 2000; accepted in revised form 4 September 2001

Key words: Acacia mearnsii, cost-benefit analysis, forestry, invasive alien species, South Africa, water resources

Abstract

Some alien tree species used in commercial forestry cause major problems as invaders of natural ecosystems. One such case, the black wattle tree, was introduced into South Africa from Australia in the 19th century. It is an important commercial species, as well as an aggressive invader, giving rise to significant environmental impacts and conflicts of interest. This paper provides an analysis of costs and benefits associated with this species in South Africa at a national level. The results suggest that a 'do nothing' scenario (with no attempts being made to control the spread of the species beyond the limits of plantations) is not sustainable, as the benefit–cost ratio is around 0.4. The most attractive control option will be to combine physical clearing and plant-attacking biological control with the continuation of the commercial growing activities. In case this is not practically feasible the next best option is a combination of seed-attacking biological control, physical control and the development of secondary industries based on wood products from clearing programmes. There is, however, a 40% loss of benefits involved with this option when compared with the first best option. The techniques used in this study, and the findings relating to the scenarios that deliver the best returns on investment, should be of broad relevance to the problem of dealing with conflicts of interest relating to invasive alien plants that have commercial value.

Introduction

Invasions by alien species are considered to be one of the largest threats to the ecosystems of the earth, and the services that they provide to humanity (Kaiser 1999). Some alien tree species used in commercial forestry and agroforestry cause major problems as invaders of natural and semi-natural ecosystems. The magnitude of the problem has increased significantly over the past few decades, with a rapid increase in afforestation and changes in land use (Richardson 1997). The species that cause the greatest problems are those that have been planted most widely, and for the longest time. In these cases, plantation forestry has (unavoidable) negative impacts, with alien species spilling over into areas set aside for conservation and water production. As plantation forestry expands, and as new species are utilized, the need for principles and protocols to regulate translocation and reduce impacts becomes more important. In a review of research needs into the deliberate introduction of species, the evaluation of potential costs and benefits of introductions, in economic, environmental and social terms, was identified as an important research question (Ewel et al. 1999). Such questions would have to be addressed in a series of case studies, and the case of black wattle (*Acacia mearnsii*) in South Africa provides a useful starting point for addressing the development of methods to deal with this issue.

The black wattle is native to Australia, and was imported to South Africa in the mid-nineteenth century. It has been widely planted in South Africa, and now forms the basis of a small but significant industry. The species is also highly invasive and has spread over an area of almost 2.5 million ha in South Africa (Versfeld et al. 1998) where it has significant negative impacts on water resources, biodiversity, and the stability and integrity of riparian ecosystems. These two features, a commercial value on the one hand, and an invasive, damaging ability on the other, give rise to a classic conflict of interests, where the benefits accrue to a number of people, while society at large bears the external costs. The problem needs to be addressed logically and unemotionally, and this would require a balanced analysis of the costs and benefits of the species. Such an analysis could be used to inform policy decisions. While it is unlikely that policy-makers would be willing to sacrifice a vibrant black wattle industry, a way needs to be found to quantify the true costs and allocate them to the correct sources.

The South African government has proved to be serious about addressing the negative impacts of alien invading species on the natural and environmental resources of the country. However, the approach so far has concentrated on using physical methods of clearing alien plants, utilizing taxpayer's money to clear invasive stands (van Wilgen et al. 1998). Biological control (using species-specific invertebrates and pathogens from the plant's country of origin) is also a control option, but there has been considerable resistance to its use (van Wilgen et al. 2000). To date, only one such agent (a seed-feeding weevil) has been released against *Acacia mearnsii*, in areas where the wattle is not grown commercially. Plant-attacking agents could potentially also be used, although these (unlike seed-attacking agents) could kill the target plant and therefore impact severely on commercial prospects. An economic analysis of the various options available would not necessarily provide an absolute answer to the question of how to deal with these conflicts, but could give a good indication on the relative orders of magnitude of the negative and positive impacts of black wattle and ways to control invasions. The economic costs and benefits of the black wattle in South Africa need to be quantified, and options for the enhancement of positive effects, and the mitigation of negative effects, should be sought.

In this article, we estimate the costs and benefits of control options for black wattle at a national level, and explore the mitigation options that could be considered by policy-makers. In so doing, we hope to provide a basis for constructive debate on this issue, and for the establishment of an equitable and sustainable solution to the problem. Our analysis will also provide a framework within which policy-makers could assess any future proposals to introduce new species, which could have similar impacts. Such introductions are constantly being made without consideration of future impacts, and equitable ways of applying mitigation could be agreed upon prior to the establishment of vested interests.

The black wattle in South Africa

The black wattle is a tree that reaches a height of between 6 and 20 m. It originates from southeast Australia (Victoria to New South Wales and Southern Queensland) and Tasmania. Currently, formal wattle plantations cover 130,000 ha in the KwaZulu-Natal and Mpumalanga provinces, while earlier plantations established in the Eastern Cape Province have been abandoned. In addition, many black wattle woodlots provide rural communities with firewood. The species is also highly invasive. It produces copious amounts of hard-coated seeds which are relatively longlived, and are spread readily down water courses and through the movement of soil. Invasions are found in all areas in South Africa where the annual rainfall exceeds 500 mm. The provinces mostly affected are the Western Cape, Eastern Cape, KwaZulu-Natal and Mpumalanga, but parts of the Free State, Gauteng and Northern Provinces are also affected.

There are many benefits associated with black wattles in South Africa (Table 1). Many of these arise from formal plantations, but some (including firewood, charcoal and building materials) are also derived from stands of invading plants. Similarly, there are a range of negative impacts that can be attributed to both wattle plantations and invasions (Table 2); both, for example, reduce surface runoff and affect water availability, and impact on biodiversity.

Methods

We conducted a broad cost–benefit analysis (CBA), taking into account as many of the impacts and benefits associated with black wattles in South Africa (Tables 1 and 2) as possible at a national scale. Since the impacts of black wattle are diverse and many interested and affected parties were involved, a full impact analysis

Table 1. Benefits associated with the black wattle (*Acacia mearnsii*) in South Africa.

Benefit	Nature of benefit	Size of annual benefit	Net present value (1998, R6 = 1US$)
Tannins extracted from bark	Tanning agents used in the production of soft leather	154,000 t	$363 million
Other products extracted from bark	A range of products, including resins, flocculants, thinners, adhesives and dust suppressants		
Timber	Building materials and mining timber	11,000 m^3	
Pulp	Mainly exported, for the production of paper and other products	744,000 m^3	
Wood chips	Used in the production of paper		
Charcoal	Fuel for use in barbecues	98,000 t	
Firewood	An important fuel source for rural communities	161,000 t	$143 million
Building materials	Used as brandering by rural communities	9000 t	$8 million
	Used as laths by rural communities	5000 t	$5 million
	Used as poles by rural communities	10,000 t	$9 million
Carbon sequestration	Standing plantations and invasions store carbon as a counter to carbon buildups in the atmosphere, mainly from fossil fuel burning. These can potentially be traded	347,000 t C	$24 million
Nitrogen fixation	Addition of nitrogen through fixation by roots could be regarded as a benefit or a cost in some areas	Not known	Not known
Medicinal products	Possible use as styptics or astringents	Not known	Not known
Combating erosion	Planting wattles can decrease erosion in severely degraded sites away from river courses	Not known	Not known
Total			>$552 million

was seen as imperative for the success of the CBA. Our analysis was conducted in the six broad steps listed below (see, for example, Brent 1997; Winpenny 1991; Hyman et al. 1988):

- Economic (including the cost of labour) and ecological impacts of black wattle were identified.
- Impacts were prioritized, and the most serious impacts were identified
- Alternative crops to replace wattles, or substitutes for their products were identified.
- The costs and benefits of wattles and the alternative crops or products were quantified as far as possible.
- The distribution of costs and benefits was evaluated.
- Scenarios for mitigation of costs and benefits were formulated and subjected to sensitivity analysis on key uncertainties.

Identification and prioritization of impacts

The first two steps in our analysis involved the identification and prioritization of impacts. These were identified in three ways. First, the ecological impacts of black wattle were assessed from a survey of available literature, and this was backed up by a questionnaire survey conducted among experts. Second, we assessed the impacts and benefits to rural communities in a case study in a rural area. Finally, we gathered information on the industry benefits derived from black wattle from a series of consultations with the South African Wattle Growers Union.

The questionnaire survey, designed to assess the relative importance of ecosystem impacts in the short, medium and long term (defined as <1 year, 1–5 years and >5 years), was sent to 43 experts in March 1998. The issues addressed were identified by means of a literature survey, and from our own understanding of the problem. On the basis of this, impacts on streamflow amount, streamflow quality, biodiversity, erosion and fire control were included in the questionnaire. The questionnaire tested both for opinions on the expected magnitude of the impacts, and the likelihood that they would occur. The advantages of a questionnaire approach include the low cost of establishing the relative importance of impacts, and the ability to estimate probabilities at different time intervals. The disadvantages include an inability to model interactions and feedbacks between the answers obtained, the fact that it is only possible to obtain ordinal values (as opposed to direct costs), and an inability to interpret the reasons for respondents expressing certain views. The results of the survey, however, gave a good indication

Table 2. Negative impacts associated with the black wattle (Acacia mearnsii) in South Africa.

Impact	Nature of impact	Size of impact	Net present value (1998, R6 = 1US$)
Reduction of surface streamflow	Increases in the height and biomass of vegetation increase rainfall interception and transpiration, and decreases streamflow	Losses due to invasive wattles estimated at 577 million cubic metres of water annually (Versfeld et al. 1998)	$1425 million
Loss of biodiversity	Displacement of species-rich indigenous plant communities by single-species wattle stands, and disruption of important ecosystem processes	Almost 1900 of the 3435 plant species in the South African Red Data List are threatened wholly or in part by all alien invading plants	The economic value of biodiversity is poorly understood, but is believed to be significant (Costanza et al. 1997)
Increases in fire hazard	Increases in biomass lead to increases in fuel loads, while dense stands of invasive trees hamper access for fire management purposes	Fuel loads are often increased 10-fold (Versfeld and van Wilgen 1986; van Wilgen and Richardson 1985), leading to increases in fire intensity and damage due to fires	$1 million
Increases in erosion	Increases in fire intensity lead to soil water repellency and increased erosion after fire	Studies have demonstrated that soil loss increases 20–60-fold after fire in grassland and fynbos catchments afforested with pines (Scott and van Wyk 1990)	The loss of irreplaceable surface soil will have economic consequences
Destabilization of river banks	Invasion of riverbanks causes deep channelling followed by slumping during floods	All invaded rivers affected to some extent	Not known
Loss of recreational opportunities	Invasive plants along riverbanks can reduce access for anglers, canoeists, white-water rafters and swimmers	Not known, but fly-fishing attracts large numbers of influential followers who invest significant sums in the sport	Could be estimated by willingness-to-pay, but no estimates currently available
Aesthetic costs	Invasive plants detract from the wilderness character of many rural landscapes and conservation areas	Not known, and would depend on the observer's awareness of the problem	Could be estimated by testing perceptions, but no estimates currently available
Nitrogen pollution	Increases in soil nitrogen levels in nutrient-poor environments can make habitats unsuitable for indigenous plants and more susceptible to invasion by other species, reducing biodiversity	Almost 2.5 million ha have been invaded in South Africa (Versfeld et al. 1998)	No estimates available
Loss of grazing potential	Competition between invasive wattles and important grazing grasses reduces grass cover	Affects rural communities in grassland areas in the Eastern Cape, Mpumalanga and KwaZulu/Natal provinces	94% of households reported this as a significant factor (this study)
Total			>$1426 million

on the relative importance of the selected ecological parameters and the relative impact of various control options. A weighted score was attached to ecological parameters through multiplying their impacts with the probabilities assigned by respondents to these impacts in the short, medium and long terms; this in turn was used to assign priorities to the impacts identified.

The case study aimed at establishing the costs and benefits of wattles was carried out in six rural villages in the KwaZulu-Natal province. A series of questionnaires were designed to capture the salient information. A series of qualitative supplementary questionnaires were also used in group interviews or in support of participatory research workshops (Hansman 1999). A total of 36 questionnaires were completed in each of the six villages, giving a total of 108 households surveyed. The survey was stratified to ensure that a random sample was achieved.

In order to assess the benefits arising from commercial forestry and small growers, we collected data during a series of interviews with members of the South African Wattle Growers Union. We adopted a Value Added (VAD) (SARB 1999) approach in order to inform the CBA. Under the VAD approach, wages, representing compensation for the value they add to economic wealth, are included as a benefit, while under traditional CBA approaches, they are regarded as a cost. The inclusion of job-creation as a benefit is seen as advantageous in South Africa, where unemployment is high, and the importance of developing human capital is implicitly recognised. The value added per hectare (including a price for labour) was calculated and multiplied with the economic multiplier to estimate the effects on national income. A multiplier of 1.28 is used, which is based on a Keynesian macroeconomic demand model comprising consumption, investment, government and external sectors. The wage bill accounts for almost 47% to value-added per hectare.

The wattle industry has grown by 5.1% per year over the past 10 years, but it is not clear whether this rate of growth will be sustained over the next 20 years (the timeframe adopted for this study). Given the existing uncertainties around the market demands for products and the limited new areas available for planting, we assumed a future growth rate of 2.55% over the next 20 years, half the growth realised between 1989 and 1998.

Alternatives to wattle plantations and wattle products

We assessed the value of alternatives to the growing of wattle as a crop, and the costs of using alternative products in the event of wattles not being available, in order to establish opportunity costs. These are defined as the costs or benefits associated with the next best alternative, should wattles not be available as an option. In the case of formal wattle growers, we identified a range of crops as alternatives, including various types of maize, various types of beans, sunflowers, and afforestation with either eucalypts or pines. In the case of rural communities dependent on wattles for their fuel and energy needs, we identified electricity, paraffin, firewood from indigenous forests, and firewood from other, non-invasive alien species as alternatives. The last two, plus purchase of formal building materials, were also considered as alternatives in the case of building materials.

Quantification of costs and benefits

We calculated a cost–benefit ratio for a ‘do nothing’, or ‘business as usual’ scenario, where commercial activities around the growing of wattles continued, and no attempts were made to control the invasive plants that continue to spread around the country. The various impacts and benefits (Tables 1 and 2) for this scenario were quantified and where monetary values or proxy prices were not readily available for a particular benefit or impact, we made explicit assumptions in order to be able to calculate benefits and costs (for example, there are good data on the value of bark and timber products, but the actual value of biodiversity is difficult to quantify). We then compared these cost–benefit ratios with ratios derived under a range of other scenarios where different combinations of control options would apply (Table 3). The costs and benefits of the ‘business as usual’ scenario were calculated assuming that current infestations of invasive wattle remained in existence, while the costs and benefits associated with the mitigation scenarios were constructed assuming that 100% of invasive black wattle would be removed over a 20 year time horizon. The time period was set at 20 years, which is the estimated time needed for clearing existing infestations and doing the necessary follow-up in the physical clearance control option. Any potential costs incurred after 20 years have not been included in the analysis.

Where costs and benefits were compared, the base year was set at 1998 when clearing operations began in earnest. Where information was only available for other years, figures were adjusted to reflect 1998 values. Inflation was set at an average of 8% for the next 20 years, as was the discount rate for net present value (NPV) calculations.

The size of benefits to rural communities depends on the number of beneficiaries. In the calculation of rural benefits we assumed a 2% average annual population growth over the next 20 years, which is lower than the current average rate between 1996–2001 of 2.2% (SSA 1999), to take account of the likely impacts of HIV/AIDS. Based on assumptions on the access of rural population to black wattle resources, it was calculated that 35% of the rural population use black wattle as a resource.

Estimates based on International Panel of Climate Change (IPCC) guidelines were used for the calculation of carbon sequestration benefits (Scholes 1997). Based on this methodology the average carbon uptake

Table 3. Scenarios outlining potential approaches to the management of black wattles in South Africa.

Scenario	Description	Implications
Business as usual (do nothing)	Commercial activities continue, and no attempts are made to control invasive plants	Water loss and environmental impacts grow as invasive plants continue to spread. Commercial benefits unaffected
Physical clearing	Commercial activities continue, and invasive plants controlled by felling, herbicide treatment, and follow-up	Water loss and environmental impacts avoided, but clearing costs are high. Commercial benefits unaffected
Combination of biological control (seeds) and physical clearing	Commercial activities continue, and invasive plants controlled by felling, herbicide treatment, and follow-up, and seed-feeding biocontrol insects are released	Water loss and environmental impacts avoided, and follow-up costs are reduced once initial infestations are cleared. Commercial benefits unaffected
Combination of biocontrol (plants), assuming commercial growers can protect plantations at a low cost	Invasive plants controlled by biocontrol agents that kill trees, and this can be countered effectively by growers. The need for physical control declines sharply	Long-term water loss and environmental impacts avoided at minimal cost. Commercial interests impacted, but not to a great extent
Combination of biocontrol (plants), assuming commercial growers can protect plantations at a high cost	Invasive plants controlled by biocontrol agents that kill trees. Wattle growers can only control this situation at a high cost. The need for physical control declines sharply	Long-term water loss and environmental impacts avoided at minimal cost. Commercial interests severely impacted
Combination of better plantation management and physical clearing	Commercial activities continue with improved management of invasions on plantation estates. Invasive plants controlled by felling, herbicide treatment and follow-up outside plantations	Water loss and environmental impacts avoided, but clearing costs are high. Commercial benefits reduced slightly due to higher management costs
Combination of secondary industry and physical clearing	Commercial activities continue, and invasive plants controlled by felling, herbicide treatment, and follow-up. Secondary industries that will utilize the products of cleared areas are developed	Water loss and environmental impacts avoided, and high clearing costs offset to some extent by sale of products. Commercial benefits unaffected
Combination of biocontrol (plants), assuming commercial growers unable to effectively protect plantations	Invasive plants controlled by biocontrol agents that kill trees. Growers unable to protect plantations from biocontrol agents	Long-term water loss and environmental impacts avoided at minimal cost. Commercial interests probably curtailed

The scenarios were used as a basis for the calculation of cost–benefit ratios.

from 130,000 ha of wattle plantations is 347 kt C/year. Baseline economic costs of CO_2 were based on very conservative international estimates of US$ 5.30/t C for the period 1998–2000, US$ 6.80/t C for the period 2001–2010 and US$ 8.60/t C for the period 2011–2018 (World Bank 1994). As it is unlikely that wattle infestations outside of formal plantations will be seriously considered as tradable on a carbon market, these were not considered in the analysis.

Streamflow loss was estimated through assigning a base runoff : rainfall ratio to GIS grid cells. Reductions in this ratio were then calculated based on estimates of wattle biomass (for which rough estimates of the spatial distribution were known, Versfeld et al. 1998), following the methods described by Le Maitre et al. (1996). The economic value of streamflow loss was calculated using the opportunity-cost approach. First, the value added by water over the different demand sectors (irrigation, domestic and urban use, mining and industry, the environment and afforestation) was calculated. Second, the value added by additional water where black wattles were eradicated was estimated. These estimates are adjusted for to allow for evaporation and spillage of flood water (33% of additional water was assumed to be unusable), changes in the numbers of downstream water users over the next 20 years, and the degree to which water would contribute to the economic value added in each sector (assumed to be 10% of predicted growth in economic value added).

Infestations of wattle and other invasive plants are expected to increase the costs of fire management. Estimates of fire management costs were derived from the literature (van Wilgen 1981) and adjusted for 1998 values. The incremental costs in fire management due to wattle invasions were calculated by assigning an incremental cost of 5%. This is based on the understanding that black wattle will increase fire hazard in extreme weather conditions (van Wilgen and

Richardson 1985). It was also assumed that only 10% of the total black wattle area in South Africa is likely to lead to an increase in fire management costs. These assumptions are considered to be very conservative, and they resulted in very small estimated total costs when compared to those estimated for streamflow loss.

Scenarios for mitigation

In addition to the 'do nothing' scenario, we identified a range of scenarios that could constitute viable alternatives for consideration by policy-makers. These scenarios (Table 3) were then used as a basis for the calculation of cost–benefit ratios, using the methods described above. The relative impacts of these scenarios were compared in terms of the benefit–cost ratios that they generated. These ratios accounted for all of the benefits and costs associated with each scenario, including, for example, the industrial and social benefits lost (such as loss of income from commercial activities, of rural benefits and of opportunities for carbon sequestration) and the social benefits created (such as more streamflow, and less fire hazard). The results were also subjected to a sensitivity analysis to examine the relative importance of the assumptions made in each of the scenarios. The sensitivity tests are biased towards the value of goods and services, as underlying population dynamic models were not developed in detail. More research is needed on the effectiveness and population dynamic models of especially those relating to the effects of plant-attacking biocontrol agents (De Wit et al. 2000).

Results

The costs and benefits associated with the 'do nothing' scenario (Table 4) show that costs exceed benefits, resulting in benefit–cost ratios of <1. In the 'do nothing' scenario, only the quantifiable costs and benefits were taken into account, and the benefits and costs associated with unquantified elements such as biodiversity conservation, recreational opportunities and aesthetic impacts were not considered. According to these results, the 'do nothing' scenario incurs around twice as much costs as the benefits it delivers to the country as a whole, indicating an unsustainable situation.

Similar benefit–cost ratios were calculated for the remaining scenarios (column I in Table 5). We then subjected each of these scenarios to a sensitivity analysis on key uncertainties, in order to establish whether changing any of the assumptions about values associated with costs and benefits would affect the ranking of scenarios in terms of their attractiveness. The results are reflected in columns II–VIII of Table 5. Based on these results it can be argued that the baseline estimations are remarkably robust as the relative rankings of the most viable mitigation options remained more or less constant in spite of changes to the assumptions.

Discussion

Limitations of the research approach

Cost–benefit analysis has several weaknesses, including the use of aggregated indices, the calculation of social utility functions, NPV calculations and the choice of the discount rate and the distribution of costs and benefits. Although these criticisms are justified, CBA is still an important tool for informing decisions, while not necessarily prescribing them. A well-constructed CBA gives an indication on the order of magnitude of costs and benefits and has the advantage of identifying unviable alternatives early on.

The boundaries of a CBA have to be clearly defined before the study commences in order to make the costs and benefits of different alternatives comparable. Our

Table 4. The costs and benefits (millions of US$) associated with a 'do nothing' scenario (Table 3) with regard to the management of black wattles in South Africa.

	Benefits to commercial growers	Benefits to rural users	Benefits from carbon storage	Cost of lost streamflow	Cost of increased fire hazard	Benefit–cost ratio
1998 values	30.7	14.2	1.8	78.7	0.03	0.6
Average annual value over 20 years	39.3	17.3	2.5	158.5	0.15	0.4
Net present value	363	149.3	24	1370.8	1.1	0.4

Only quantifiable costs and benefits were considered. An 8% discount rate was used to calculate net present value.

Table 5. The benefit–cost ratios (based on net present value over 20 years) associated with a range of management scenarios (Table 3) with regard to the management of black wattles in South Africa.

Scenario	Sensitivity analysis (see footnotes)							
	I	II	III	IV	V	VI	VII	VIII
Do nothing	0.4	1.1	0.5	0.4	0.4	0.3	0.4	0.4
Physical clearing	3.2	1.0	3.2	3.2	3.2	4.5	3.2	3.2
Combination of biological control (seeds) and physical clearing	4.1	1.1	4.1	4.1	4.1	5.8	4.1	3.7
Combination of biocontrol (plants) and physical clearing, assuming commercial growers can protect plantations at a low cost	7.5	1.2	7.5	4.0	7.5	10.7	7.5	7.5
Combination of biocontrol (plants) and physical clearing, assuming commercial growers can protect plantations at a high cost	4.0	1.0	4.0	2.8	4.2	5.7	4.0	4.0
Combination of better plantation management and physical clearing	2.5	0.7	2.5	2.5	2.5	3.0	2.5	2.5
Combination of secondary industry and physical clearing	3.2	1.0	3.2	3.2	3.2	4.5	4.2	3.2
Combination of biocontrol (plants), assuming commercial growers unable to effectively protect plantations	2.4	0.9	1.8	1.9	2.4	3.5	2.4	2.4

An 8% discount rate was used to calculate net present value. The columns indicate different assumptions (see below), and provide a sensitivity analysis.

I. Only quantifiable costs and benefits included.

II. Highest estimates of rural use of wood products and unit prices, and assuming that 50% of rural population in wattle areas have viable access to black wattle resources.

III. High estimate of potential carbon sequestration benefits to commercial growers.

IV. Plant-attacking biocontrol agents 38% effective. The remaining plants need to be physically cleared.

V. Maximum 'willingness to pay' for defense against biocontrol agents estimated at R42 million.

VI. Including an estimate of R100 million for the value of biodiversity and an estimated growth rate of this value of 5%.

VII. Include secondary industry valued at R182 million per annum at 5% growth over the next 20 years.

VIII. Rate of spread in case of seed-attacking biocontrol only reduced to 2% per annum, compared to 0% per annum in baseline case.

study was limited to a national level of analysis, to avoid falling into the complexities of area-specific costs and benefits of black wattle. It is thus possible that regional differences (for example localized concentrations of biodiversity, or differences in growth potential for wattles) may have been masked in our study.

It was assumed that the invasions of black wattles would increase, if not controlled, by 5% per year, and that the associated impacts will also increase. For example, Le Maitre et al. (2001) estimated that current infestations in selected catchment areas in South Africa were currently using between 6% and 22% of the surface runoff. If interventions in the form of control programmes were not introduced, then the invasions would continue to spread over the next 13–63 years, at which time they would occupy all of the suitable habitat and increase water use to between 22% and 95% of the surface runoff. In addition, estimated control costs would increase by orders of magnitude (between 168% and 6780%) over the same period. Ideally, these important dynamics should be considered in combination with the timing of control interventions, to gain a full understanding of the costs and benefits. Nonetheless, we believe our analysis has been useful in illustrating the principal costs and benefits.

Finally, it was not possible to study all impacts or benefits at the same degree of detail. A ranking of potential impacts was therefore done to allocate time and resources as cost-effectively as possible. In the absence of clear data on valuations, the ranking was reliant on expert opinion. The absence of information on certain key impacts or benefits limits the validity of our findings. Examples are, information on the population dynamics of biocontrol agents, information on ecological impacts associated with black wattle (and ecological thresholds), and future expected trends in the commercial black wattle industry. These are common problems, especially in developing countries. Nonetheless, we feel confident that we have at least identified a valid set of options that can provide a useful basis for taking this debate further.

Sensitivity of the models to changes in base assumptions

A range of changes to the base assumptions (indicated in columns II–VIII in Table 5) provides some insight into the sensitivity of the various models to these changes. The benefit–cost ratios in column II suggest that the outcomes are particularly sensitive to rural use values, as the highest estimates are far less than those associated with baseline calculations (column I in Table 5). The higher the amount of wattle products used and the unit price for these resources, the higher the ratios of options that do not have the potential to eradicate wattles. However, despite the huge increase in rural use values, the option to use plant-attacking biocontrol with a small increase in industry expenditure is still the best, although at a much lower ratio than in the baseline scenario. Obviously, if people everywhere made use of wattle products at high unit prices from infested areas, this case would hold. However, it is unlikely that a combination of such high levels of use and high values would exist in many areas, making the assumption less valid.

Although not shown in Table 5, the model was not sensitive to changes in either the value of the black wattle industry or the estimated growth rate of the industry over the next 20 years. The value of the industry would have to increase 10-fold and the rate of growth 5-fold to reach benefit–cost ratios comparable to the best in the scenario where only quantifiable costs and benefits are included. Such rates of growth are highly unlikely.

Changes to the value of carbon sequestration benefits (column III in Table 5) indicate a marginal improvement in the benefit–cost ratios. When one of the highest estimates of carbon sequestration benefits was used (World Bank 1994), the ratio improved marginally, while the mitigation scenario of combined biocontrol, assuming that commercial growers would not be able to protect their plantations, was less than in the baseline scenario (column I). However, the rankings of the best mitigation options remained unchanged relative to the base case.

The effectiveness of plant-attacking biocontrol would have to decrease to an unrealistic 38% (instead of the 95% assumed in the baseline case) before a change in the ranking of the two best mitigation options take place (column IV in Table 5). In such a case it would be better to combine seed-attacking biocontrol and physical clearing.

The more that commercial wattle growers are willing (or able) to pay for the protection of their plantations against plant biocontrol agents, the less attractive this option becomes (column V in Table 5). The ranking of the best three mitigation options starts to change when growers would be willing or able to pay US$ 7 million/year or less. At this point, the plant-attacking biocontrol combined with high protection costs for plantations became the second best option, replacing the combination of seed-attacking biocontrol and physical clearing. The best option (plant-attacking biocontrol combined with low protection costs for plantations) was still 1.8 times better then the next best option.

The order of scenarios proved not to be sensitive to the inclusion of an economic value for biodiversity, but the ratios were higher for all the mitigation options when compared to baseline estimations (column VI in Table 5). The 'do nothing' scenario became worse as more benefits were attributed to biodiversity.

In order to make the combination of physical control and secondary industry the second best mitigation option, the additional value added by such industries would have to exceed US$ 30.3 million per annum, and the industries would have to grow at a rate of at least 5% per annum (column VII in Table 5).

The impact of assumptions about the degree to which the release of a biocontrol agent would impact on the spread of invasive wattles was examined in column VIII of Table 5. A less effective seed-attacking biocontrol agent, which would allow a higher rate of spread (2%, compared to 0% in baseline) would decrease the acceptability of the combined physical control and seed-attacking biocontrol option, with the two combined biocontrol options the best options, available in such a scenario.

Distribution of costs and benefits

One way of categorising user groups is to broadly define them as those that consume black wattle products, and those that do not (Table 6). Commercial wattle growers, small growers and rural communities that benefit from the products of invasive wattles would be included under consumptive users. Non-consumptive users are those reliant of a clean and healthy ecosystem and the services they deliver in the form of water, recreation and biodiversity; this group includes most sectors of society. Potential other land users are also a non-consumptive group. Other land users would include those interested in the land under the black wattle trees, but could also include groups experiencing black wattle impacts as negative, for example, in an aesthetic way.

Commercial wattle growers and woodlot owners enjoy both the financial benefits of black wattle and the potential benefits of carbon sequestration (which are

Table 6. The distribution of costs and benefits associated with black wattles in South Africa.

Relationship with wattles	User sector	Gains commercially from wattles?	Gains in other ways from wattles?	Carries the costs of wattles?	Suffers lost opportunities with respect to land use due to invading wattles?
Consumptive users	Commercial growers	Yes	Yes	No	No
	Rural communities that utilize wattle products	No	Yes	Yes	Yes
Non-consumptive users	Users of ecosystem services	No	No	Yes	No
	Potential users of invaded land	No	No	Yes	Yes

potentially marketable). Users of ecosystem services bear the social costs of a loss in water and biodiversity, an increase in fire hazard and the impacts of erosion. Rural communities enjoy the social benefits of economic value of black wattle products, but do bear the same social costs to the ecosystem as ecosystem users (although the latter is not always perceived to be a problem in rural communities). Other land users bear the costs of flood damage, a loss of recreation and aesthetic impacts as well as the opportunity costs of black wattle instead of other land-uses.

Implications of the results

The results of a CBA suggest that the options for dealing with wattles in South Africa are relatively clear. A scenario of business as usual (do nothing) is not viable, and any of the other scenarios would be preferable. The best option (combining biocontrol of plants, as opposed to biocontrol of seeds only, with growers able to protect plantations from these agents at low cost), where benefits are more than seven times larger than costs, may not be practically feasible. This is because the agents are not identified at present, and there may not be effective protection against them. The next best option, combining biological control using seed-feeding biocontrol agents with physical control (Table 5) would represent the most practical solution to the conflict at this stage, and would deliver benefits estimated at four times greater than the costs. Combining this option with the development of secondary industries (a scenario that we did not explicitly test) could conceivably produce even larger benefits. The important point is that investment in overcoming the practical problems of the first best option warrants serious attention, as more than 40% of potential benefits can be lost by implementing the second best control option.

Another implication is the need to align the costs of control more strongly with the beneficiaries of wattle products. Until recently, wattle invasions were allowed to grow without any clearing programmes in place, so no clearing costs were being incurred. Currently, the cost of clearing (not shown explicitly in Table 6) is borne by taxpayers in South Africa. The beneficiaries of wattle products (commercial growers and rural communities) do not pay for such impacts despite the relatively large share of the gains that they enjoy. Given the unsustainable nature of a ‘do nothing’ scenario, ways will have to be found of sharing the costs of clearing in an equitable way. The question on the amount of responsibility for different interest groups has not been answered in this paper. While it is unlikely that commercial growers will ever be required or able to carry the costs of clearing the vast invaded areas around the country, they could contribute meaningfully through, for example, supporting a research programme aimed at finding acceptable biological control solutions. In the past, such programmes have been actively resisted by growers (Stubbings 1977), but given the attractive national benefit–cost ratios associated with such programmes, and their affordable nature, such support would not be an unreasonable requirement.

Besides research on suitable biocontrol options, this study has highlighted a number of areas where further research would improve the CBA. These include studies aimed at the valuation of benefits arising from biodiversity and ecosystem services, practical ways to implement plant-attacking biocontrol, and if this is not feasible, opportunities to develop secondary industries. The availability of good valuation data could be used to refine this and similar models, thus enabling policy-makers to base their decisions on improved analyses. While the options available for dealing with problems associated with wattles may be limited due to strong and entrenched interests, the same does not necessarily hold for the introduction of new species. For example, growers are currently testing a range of related *Acacia* species for possible commercial planting in South Africa (Dunlop 1998). Many of these are potentially as invasive as *Acacia mearnsii* (or worse), and it would make sense to identify and agree upon the mitigatory options and responsibilities for funding them, prior to permitting their release. Techniques such as those described in this paper could be very useful in supporting such a process.

Both the techniques used in this study, and the findings relating to the scenarios that deliver the best returns on investment, should be of broad relevance to the problem of dealing with conflicts of interest relating to invasive alien plants that have commercial value. As plantation forestry grows in importance, it will be necessary to deal with these conflicts as trees escape and invade surrounding areas, with negative consequences. Studies of the costs and benefits of invasions of such commercially important species will show whether the initiative delivers more than it costs, and it will help policy-makers identify the management scenarios that will deliver the best results. It will also assist in developing policies for dealing with the problems of invasion upfront, before they occur, thus avoiding the current situation that prevails in many places, where the responsibility for dealing with the invasive problem is illdefined and difficult to deal with in a posthoc manner.

Acknowledgements

We thank the Canadian IDRC and the South African Department of Water Affairs and Forestry's Working for Water Programme for funding this work. We also thank those experts who participated in our questionnaire survey, and the staff of the South African Wattle Growers Union for supplying information and commenting on an earlier draft of the paper. The results presented here are not necessarily those of anyone we consulted, and they remain the responsibility of the authors.

References

Brent RJ (1997) Applied Cost–Benefit Analysis, paperback edition, reprint. EdwardElgar, Cheltenham, UK

Costanza R, d'Arge R, de Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P and van den Belt M (1997) The value of the world's ecosystem services and natural capital. Nature 387: 253–260

De Wit MP, Crookes DJ and Geach BGS (2000) The Costs and Benefits of Black Wattle in South Africa. CSIR Report ENV-P-C 2000-023, Pretoria

Dinwiddy C and Teal F (1996) Principles of Cost-Benefit Analysis for Developing Countries. Cambridge University Press, Cambridge

Dunlop R (1998) Genetic improvement of *Acacias.* Annual Research Report of the Institute for Commercial Forest Research, ICFR, Pietermaritzburg, pp 38–44

Ewel JJ, O'Dowd DJ, Bergelson J, Daehler CC, D'Antonio CM, Gomez LD, Gordon DR, Hobbs RJ, Holt A, Hopper KR, Hughes CE, LaHart M, Leakey RRB, Lee WG, Loope LL, Lorence DH, Louda SM, Lugo AE, McEvoy PB, Richardson DM and Vitousek PM (1999) Deliberate introductions of species: Research needs. BioScience 49: 619–630

Hansman C (1999) A Socio-Economic Assessment of the Working for Water Projects, DRA Development Report 99/1

Hyman EL, Stiftel B, Moreau DH and Nichols RC (1988) Combining Facts and Values in Environmental Assessment. Theories and Techniques. Social Impact Assessment Series, No. 16, Westview Press, Boulder, Colorado, London

Kaiser J (1999) Stemming the tide of invasive species. Science 285: 1836–1841

Le Maitre DC, Van Wilgen BW, Chapman RA and McKelly DH (1996) Invasive plants and water resources in the Western Cape Province, South Africa: modelling the consequences of a lack of management. Journal of Applied Ecology 33: 161–172

Le Maitre DC, Van Wilgen BW, Gelderblom CM, Bailey C, Chapman RA and Nel JA (2001) Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. Forest Ecology and Management (in press)

Richardson DM (1997) Forestry trees as invasive aliens. Conservation Biology 12: 18–26

Scott DF and van Wyk DB (1990) The effects of wildfire on soil wettability and hydrological behaviour of an afforested catchment. Journal of Hydrology 121: 239–256

South African Reserve Bank (SARB) (1999) Quarterly bulletin No. 214. SARB, Pretoria

Statistics South Africa (SSA) (1999) Stats in Brief 2000. SSA, Pretoria

Stubbings JA (1977) A Case Against Controlling Introduced Acacias (ACACIA). South African Forestry Journal 102: 8–14

Van der Merwe MR and Scholes RJ (eds) (1999) South African greenhouse gas emissions inventory for the year 1990. CSIR Report, ENV-P-C 99049, Pretoria

van Wilgen BW (1981) An analysis of fires and associated weather factors in mountain fynbos areas of the South-Western Cape. South African Forestry Journal 119: 29–34

van Wilgen BW and Richardson DM (1985) The effects of alien shrub invasions on vegetation structure and fire behaviour in South African fynbos shrublands: a simulation study. Journal of Applied Ecology 22: 955–966

van Wilgen BW, Le Maitre DC and Cowling RM (1998) Ecosystem services, efficiency, sustainability and equity: South Africa's Working for Water programme. Trends in Ecology and Evolution 13: 378

van Wilgen BW, van der Heyden F, Zimmermann HG, Magadlela D and Willems T (2000) Big returns from small organisms: developing a strategy for the biological control of invasive alien plants in South Africa. South African Journal of Science 96: 148–152

Versfeld DB and Van Wilgen BW (1986) Impacts of woody aliens on ecosystem properties. In: Macdonald IAW, Kruger FJ and Ferrar AA (eds) The Ecology and Control of Biological Invasions in South Africa, pp 239–246. Oxford University Press, Cape Town

Versfeld DB, Le Maitre DC and Chapman RA (1998) Alien Invading Plants and Water Resources in South Africa. A Preliminary Assessment. Report to the Water Research Commission. CSIR No. ENV/S-C 97154. WRC Report No. TT 99/98 September.

Winpenny JT (1991) Values for the Environment. A Guide to Economic Appraisal. HMSO, London

World Bank (1994) Global Warming. Measuring the Costs. Dissemination Notes. World Bank, Washington, DC