Economic evaluation of the management of bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) to conserve native plant communities in New South Wales

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Summary

The bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) T.Norl.) Threat Abatement Plan (TAP) aims to reduce the impacts of bitou bush on biodiversity in New South Wales. This is the first weed TAP in Australia and so its effectiveness in conserving threatened biodiversity, as well as its cost of implementation, must be examined to determine if this new approach should be adopted as a template for managing the biodiversity impacts of other major weed species. We therefore consider the question 'is the TAP a good investment in relation to protecting biodiversity'? We combine the costs of implementing the TAP with conservative, published estimates of the benefits of protecting biodiversity, to calculate the benefit-cost ratios of the investment. The ratios indicate that the benefits of the TAP exceed the costs under a wide range of economic conditions. While this result supports the approach, the cost of implementation should be analysed over the five years relative to the biodiversity outcomes in order to determine the *ex post* benefit of the TAP.

Introduction

Bitou bush arrived in Australia from South Africa about 1908 and has now spread to 80% of coastal New South Wales (DEC 2006). In 1999, the weed was listed as a key threatening process under the NSW *Threatened Species Conservation Act 1995* and in accordance with the Act, a Threat Abatement Plan was prepared to reduce, abate or ameliorate the threat of bitou bush on coastal biodiversity (DEC 2006). The cost of implementing the TAP in 2005–06 was estimated to be $2.85m, a cost that should continue over the five years of the plan's implementation. Is this cost a good investment in relation to the biodiversity that is protected? The objectives of this paper are therefore to (i) assess the economic desirability of the TAP, and (ii) further develop the method for these kinds of evaluation.

Methods

The steps for evaluating the TAP follow the standard procedures of benefit-cost analysis (see Sinden and Thampapillai (1999), for further details).

(a) Define the problem and the management strategy

The problem is the threat posed by bitou bush to native plant communities in New South Wales. The TAP is a management strategy to address the problem, which aims to protect 158 plant species and 28 ecological communities at over 300 sites along the entire New South Wales coastline. The TAP comprises various actions including on-ground control, monitoring the response of bitou bush and native species to control, and co-ordination of on-site and between-site management to implement the plan. The analysis must answer the question, 'do the benefits of the TAP exceed the costs'? The benefit is the value gained from the protection of biodiversity from bitou bush, and the costs are the resources invested to achieve this benefit.

(b) Define the nature and value of the costs

The costs include cash expenditure, external grants, and in-kind contributions, so the total cost is defined as:

$$\text{Total cost} = \text{cash expenditures} + \text{external grants} + \text{in-kind costs} \qquad (1)$$

The external grants are income from other state and Commonwealth agencies such as the National Heritage Trust. The in-kind costs include volunteer labour costed as the number of volunteer hours multiplied by an hourly wage rate, government agency and other staff time and the associated on-costs (e.g. office space, phones, computers, and vehicles).

The total cost of implementing the TAP in 2005–06 was $2 845 500, which is estimated to remain at a similar level for each of the five years of the TAP (DEC 2006). The costs of all on-ground activities, including direct control, monitoring, and preparation of site-specific plans, was $2 489 000 for each year. These costs span many of the 169 priority sites in the TAP.

The costs include expenditure by the Department of Environment and Climate Change, Department of Lands, five coastal Catchment Management Authorities, the Lord Howe Island Board, numerous coastal councils and the University of Wollongong. Approximately 40 different agencies are involved in implementing the TAP. The costs include on-ground control activities, and the support activities of planning, monitoring of priority sites, training volunteers, and direct co-ordination.

(c) Define the nature of the benefits

There are two kinds of benefit derived from the TAP, namely (i) the increase in amenity from the improved access to the beaches (and the associated social values), and (ii) the increase in environmental services from the extra biodiversity that is protected. To identify the increase in environmental and social services due to the TAP, consider an area where native species are being protected for their biodiversity benefits. With the TAP we assume that the full set of current environmental and related social services will continue for the foreseeable future at the current level with a service flow of *AB* in Figure 1. If the TAP is not implemented however, the environmental services will decline following a trend such as *AC* or *AD*. Therefore the increase in benefits of full implementation of the TAP can be identified as the area *ABC* or *ABTD*, following the shape of the curve *AC* or *AD*, respectively.

Partial implementation of the TAP would lead to a decline in environmental services, giving a flow between *AB* and *AC*, rather than *AB* itself. The curve *AC* could also represent the optimal service flow without implementation. The actual service flow for *AC* in Figure 1 is based on the value of *X* in the final year, which is determined by the level of implementation and assumptions about the rate of decline of services.

(*d*) *Measure the gain in quantity of benefits*

To measure the increase in the quantity of benefits, such as *ABC*, we need to know the shape of the curve (*AC*) and the quantity of services at the end of the time horizon (*X* in Figure 1). These two data needs, and their uncertainties, can be addressed through simulations that incorporate probability distributions for the shape of the curve and the value of *X*.

The shape of *AC* can be modelled through a range of mathematical functions. The rectangular hyperbola function conveniently allows the shape and the end-point *X* to be varied to model either

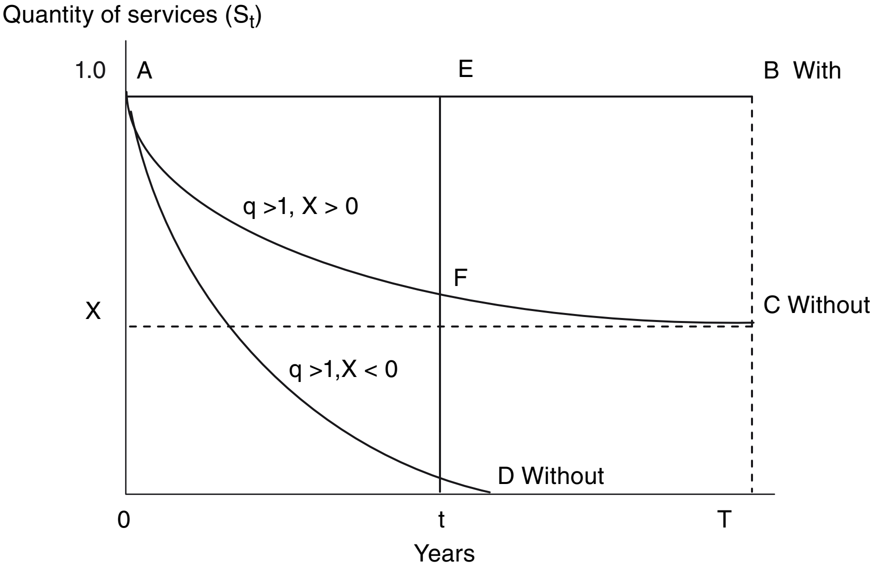

Figure 1. Flow of biodiversity services, with and without the management of bitou bush.

of the curves *AC* or *AD* in Figure 1, or any similar curve. We start by calculating the loss in benefits without the TAP, which would be *EF* at time *t*. Using the function, this loss in year *t* (L_t) is defined as:

$$L_t = (q * t) /(1+((q/m) - 1) * t) \qquad (2)$$

where *q* and *m* are parameters that are changed to vary the shape of the curve. The time *t* is coded as a proportion of 1.0, so year 2 becomes 0.1 for a 20-year time horizon. The model assumes that the weed spreads over an equal proportion of the site each year and completely covers the site by the end of the time period *T*.

We now standardize the service level at the start of year 1 to 1.0 and the level in the final year *T* to *X*. The actual service level (*S*) that remains in year *t* (S_t) is equal to ($1-L_t$). So the standardized value of the service flow (S^*) in each year *t* is derived as:

$$S^*_t = ((1-L_t) + X)/((1-L_0) + X) \qquad (3)$$

where L_0 is the loss in year 0 which is the start of year 1. The service output S^* in year *t* has now been standardized to 1.0 at the start of year 1 and to a final level *X*. The standardized loss in year t (L^*_t) is therefore:

$$L^*_t = (1 - S^*_t) \qquad (4)$$

The total gain in quantity of benefits over all the years to *T* is the total loss that is avoided, so:

$$\text{Total gain in quantity of benefits} = \sum_{t=1}^{T} L^*_t \qquad (5)$$

The total gain from equation (5) is a measure of the total quantity of extra services that are due to the investment in implementing the TAP and is indexed to the value of 1.0 at the start of year one. It therefore measures area *ABC* for curve *AC*, area *ABTD* for curve *AD*, or the similar area for any other similar curve.

The total value of the gain per site can be calculated by multiplying the total gain from equation (5) by the value of the benefit (*BN*) for one unit of the gain:

$$\text{Total gain in value of benefits} = \left(\sum_{t=1}^{T} L^*_t\right).BN \qquad (6)$$

The monetary value for the total gain in benefit due to the implementation of the TAP, as defined in Equation (6), is derived from the rectangular hyperbola function of Equation (2) in which *q*, *m* and *X* can be varied. For convenience, *m* will be always be set at 1. If *q* exceeds 1 as in *AC* and *AD* in Figure 1, the changes in annual biodiversity losses or impacts are initially high but decrease with time. This trend models the later stages of a weed invasion, as argued by van Wilgen *et al.* (2004). If *q* = 1, *AC* is a linear trend that models an invasion where there is an equal loss of biodiversity services each year. If *q* is less than 1, there are small losses at first and then losses increase at an increasing rate each year as might occur in the early stages of a weed invasion without control (see van Wilgen *et al.* 2004). The decreasing trend in annual biodiversity losses seems most appropriate to the current stage of the invasion of bitou bush because of the long time it has been present as a weed, and so *q* should exceed 1.0.

(e) Value the increase in benefits

The value of a unit of the benefits (*BN*) must now be determined in order to apply Equation (6). The issues of valuing biodiversity are well discussed in the literature (see Sinden and Thampapillai 1999, for example) and thus a defensible monetary value for the flow of environmental services can be derived from the literature for the present problem. For example, Sinden and Griffith (2007) derived the value for biodiversity services from similar sites that were protected from 35 weeds in Australia. They analysed the way the costs of control varied with characteristics of the weed invasions, and determined that the costs of control increased when the number of sites threatened by a weed increased. The increase in cost for an extra site is a measure of the benefit of protecting the extra site – because costs would only be increased if the benefits increased at least as much. Their value for the benefit was $5,864 per site per year. Following economic theory, and the likely constraints on the budgets for control of each of the 35 weeds, this value represents the minimum level for the benefit. This value is used here to determine a range of values for the unit of benefit *BN*.

(f) Calculate the benefit-cost ratios

The gains and losses can readily be compared with the following benefit-cost ratio (*BCR*).

$$BCR = \frac{\text{Present value of the flow of annual benefits for all sites for } T \text{ years}}{\text{Present value of the flow of the TAP costs for 5 years}} \qquad (7)$$

A present value is the value today of a flow of future benefits, or costs, discounted at an appropriate rate. This analysis is undertaken from the viewpoint of the community, as opposed to that of the private firm, so a discount rate of 5% is appropriate and year one is taken as 2005–2006.

When the *BCR* exceeds 1.0, benefits exceed costs, when it equals 1.0 benefits equal costs, and when it is less than 1.0, costs exceed benefits. A *BCR* of 2.4, for example, reflects $2.40 worth of benefits for every dollar invested.

While the costs are given for each of the five years of the TAP, the benefits will vary with the shape of curve *AC* (as defined by *q*), the final service level *X*, and the unit value of benefits *BN*. These variations can be incorporated, and the ratios calculated, in a simulation using the @RISK software (Palisade Corporation 2002). This simulation follows five steps.

(i) *Define the data for each variable*. The costs are $2 845 000 in total, and $2 489 000 for just the on-ground control costs, for each of the first five years of the TAP. The time horizon is set arbitrarily at 20 and 50 years to reflect the short-term and long-term nature of the biodiversity benefits, and the discount rate is given at 5%. To account for the uncertainty of the shape of the curve AC, q and X are defined by probability distributions. The variable BN is also defined through a probability distribution to allow for any residual, perceived uncertainty in the monetary value of the biodiversity benefit. The triangular distribution is an appropriate, yet simple, distribution to apply because it is defined by just three values, namely, the minimum, most likely and maximum levels of each variable.

Table 1. Values to define the triangular probability distributions.

Parameters	Values		
	Minimum	Most likely	Maximum
q, gives curve like AC or AD	5	15	20
X, is the final service level	−0.10[A]	0.01[B]	0.10[B]
BN, is the value of site benefit	\$5261 (−10%)	\$5864	\$8769 (+50%)

[A] A negative value for X models curve AD that cuts the horizontal axis. The minimum value of −0.10 sets D at 16 years which is assumed to be the earliest time at any site when all biodiversity services would have been lost without the TAP. The sensitivity of the benefit-cost ratios to this subjective judgment on the time is analysed below.

[B] These two positive values for X indicate that the final service levels in year T are 1% and 10% respectively of the original level.

(ii) *A specific value is selected for each variable in the calculation*. Costs are either \$2 845 000 or \$2 489 000, the time horizon is 20 or 50 years, and the rate is 5%. For simplicity the value for m is always fixed at 1.0. We derive a value for each of the remaining variables (q, X and BN) in each calculation by sampling from their respective probability distributions (Table 1).

(iii) *A benefit-cost ratio.* The benefit-cost ratio is calculated from the set of values derived in the previous step.

(iv) *Create a range of ratios*. The third step (iii) is repeated many times (500 in this case) to give a range of ratios, which illustrates the degree of variability in the model and calculations.

(v) *Produce results*. The results are then derived from the range of ratios determined in step (iv). The results include the mean benefit-cost ratio, standard deviations, and the minimum and maximum ratios.

The TAP covers more than 300 sites, which vary in terms of (i) the number of native plant species at risk and the number of individuals of each plant species, (ii) the vulnerability of these native plants and plant communities to bitou bush invasion, (iii) the ability to achieve effective control of bitou bush, and (iv) the other threats that are present. The variety of native plants remaining at a given site in a given year is a function of all these factors, and provides the flow of biodiversity services.

This variation was explicitly modelled and tested though the changes in q and X in the simulation to allow for differences in the composition of plant communities at each site. The values adopted for these two variables followed the available knowledge. Further information on the levels of service reduction at T would help to refine estimates of X, and data on the likelihood and timing of complete extinction of the services would help to refine q. In this way we tested the importance of these particular data.

Results

The simulation produced a minimum benefit-cost ratio of 1.82, and a maximum of 3.56. Further, 90% of the ratios fell between 2.08 and 3.15, with 95% of them exceeding 2.0. The mean ratios for the two time periods and the two kinds of cost are shown in Table 2, with the standard deviations in parentheses.

The most relevant scenario comprises the total costs and a 50-year benefit flow because these attributes best model the implementation of the TAP across its range of actions and reflect the long-term benefits of these management activities. This scenario has a mean BCR of 2.56. Thus, for every dollar invested in the implementation of the TAP yields \$2.56 in return. So the annual benefit from the TAP, or its total annual economic worth, is \$7.28m (2.56 × \$2.845m). The benefits from the TAP therefore appear to exceed the costs under a wide variety of economic conditions.

The simulations provided correlations between the benefit-cost ratios and the values of the variables used to calculate them. The correlations were 88.5% between benefit value BN and the ratio, 37.6% between q and the ratio, and 31.5% between final service value X and the ratio. So the variations in the ratio depend largely on the variations of the biodiversity benefit BN rather than the shape parameter q, or the final service level X. The values for the benefit BN are taken from conservative, published, estimates derived for a similar problem in similar circumstances (Sinden and Griffith 2007).

The initial function of Equation (2) makes the restrictive assumption that the weed spreads across each site at a constant proportion of the area each year. The simulation of steps (i) to (v) allow for specified variations in the effects of each amount of spread on the output of environmental services, and so mitigates the effect of this assumption.

Table 2. Benefit-cost ratios to assess the desirability of implementing the Bitou Bush Threat Abatement Plan.

Years of benefit flow (time)	Benefit-cost ratios for	
	On-ground TAP costs	Total TAP costs
20	2.22 (0.28)	1.94 (0.25)
50	2.92 (0.38)	2.56 (0.33)

Discussion

A benefit-cost analysis assesses the contribution of a project to the increase in economic welfare, or the contribution of a problem to the loss in welfare. For example, Sinden *et al*. (2005) measured the loss in welfare in agriculture in Australia due to weed invasions. Benefit-cost analysis measures welfare as the sum of consumers and producers surplus, as set out in Sinden *et al*. (2005). If the changes in quantities of goods and services are large, we must measure the surpluses. But if the changes are relatively small in the context of the nation as a whole, as in the present analysis, welfare is equivalent to the monetary value of benefits minus the monetary value of costs.

This analysis is based on well-documented costs, a range of estimates for the benefits, and a simulation that allows for variations in the loss of the quantity of biodiversity services over time. The basic procedures, and the method for valuing the benefits, are well established (see Sinden and Thampapillai (1999), for example). The simulation addresses the uncertainty in the estimation of the loss of services in a comprehensive manner and indicates that the implementation of the TAP is economically desirable over a wide range of conditions.

The bitou bush TAP establishes a protocol for delivering biodiversity conservation through weed control (Downey 2007).

The economic evaluation is based on the 2005–06 cost of implementation, which we have assumed to be constant over the five years of the TAP. But the actual costs may vary over the years. The process for monitoring the TAP includes measuring the actual costs, thus the actual expenditures can be determined in future and the analysis can be repeated as a standard *ex post* assessment. Irrespective of these uncertainties, the Threat Abatement Plan appears to be a cost-effective strategy for protecting biodiversity and a sound investment. Given that this is the first such strategy for a weed species in Australia, such strategies should therefore be considered for other weed species that pose significant threats to biodiversity because they deliver weed control targeted at biodiversity conservation in a cost effective manner.

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Projecting the impact of climate change on bitou bush and boneseed distributions in Australia

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Summary

Global climate change will have significant implications for the management of invasive species in Australia and throughout the world. Changes to temperature and precipitation regimes may influence the fecundity, recruitment and competitive ability of invasive species leading to expansions or contractions of species distributions. Using point localities derived from the Global Biodiversity Information Facility (GBIF), and NSW National Parks and Wildlife Service survey data we have modelled projections of the potential future bioclimatic ranges of the widespread weeds bitou bush (*Chrysanthemoides monilifera* subsp. *rotundata* (DC.) Norl.) and boneseed (*Chrysanthemoides monilifera* subsp. *monilifera* (L.) Norl.) within Australia. Uncertainty exists in estimates of future climate, due to differences in projections derived from alternate climate models. Also, the severity of climate change will depend on emissions scenarios that will be influenced by human population levels, socio-economic conditions and technological changes. To address some of the uncertainty surrounding future climate, we projected species distributions onto scenarios derived from two climate models (CSIRO MK2 and NCAR) and two emissions scenarios (A1f and B1) for the year 2030. Through investigating the potential for climate change to alter the distribution of bitou bush and boneseed, managers can make informed decisions when developing strategies with a long term perspective.