Determining the cost-effectiveness of *Phytophthora cinnamomi* management in the Fitzgerald River National Park

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Abstract

The Fitzgerald River National Park is one of the world's 25 biological hotspots, containing many endemic flora and fauna species. Its unique biodiversity is being threatened by the introduced root pathogen, *Phytophthora cinnamomi*. We evaluate the cost-effectiveness of strategies to manage *Phytophthora cinnamomi* in the park, using the Investment Framework for Environmental Resources (INFFER). Management strategies based on current and higher investment levels are shown to have high Benefit Cost Indices. These results support the use of public conservation funds to address the threat of *Phytophthora cinnamomi*, and show the need for improved understanding of the impact and the adoption of strategies.

Keywords

Cost-effectiveness, economic investment framework, *Phytophthora cinnamomi*

1. Introduction

The Fitzgerald River National Park (FRNP) is located in the South-West Botanical Province of Western Australia, which is one of the world's 25 biodiversity hotspots (Myers & Mittermeier 2000). The park contains ~ 20% of the total number of plant species in WA; 62 of these are endemic, and a further 48 are more or less confined to the park (Cahill *et al.* 2008; Chapman & Newby 1995). The park supports several rare fauna, including the critically endangered western ground parrot (*Pezoporus flaviventris* North) and the endangered dibbler (*Parantechinus apicalis* Gray) (Dunne *et al.* 2011). The park is valued by the community for its recreational opportunities and provides a source of revenue to the local area from tourism (DEC 2009, unpublished data). The park is threatened by *Phytophthora cinnamomi*, which has been identified as a significant management concern (CPSM 2009; Moore *et al.* 1991). Cahill *et al*. (2008, p. 291) have speculated that infestation of the park by *Phytophthora cinnamomi* could be the "greatest biodiversity catastrophe in Australia".

The root pathogen *Phytophthora cinnamomi* is a major problem in Australia because of its harmful effects on native and commercial plant species (Cahill *et al.* 2008). Disease caused by the pathogen was listed as a key threatening process under the Commonwealth's

Environment Protection and Biodiversity Conservation Act in 2000 (DEH 2002). The pathogen's impact is particularly severe in the South-West Botanical Province. This is chiefly due to the area's favourable environmental conditions, and to the large number of plant species which are vulnerable to the pathogen (Cahill *et al.* 2008; Lewis & Colquhoun 2000). It has been estimated that 40% of plant species in the South-West Botanical Province are susceptible to *Phytophthora cinnamomi*, and 14% are highly susceptible (Shearer *et al.* 2004). The pathogen has been described as an "unparalleled example of an introduced pathogen with wide host range causing immense irreversible damage" in the south-west of Australia (Shearer *et al.* 2004, p.8). *Phytophthora cinnamomi* prevents infected plant species from drawing up water and nutrients, resulting in the death of susceptible plants (Cahill *et al.* 2008; Lewis & Colquhoun 2000). This effects the structure and function of plant communities, and ultimately leads to a loss of biodiversity (Shearer *et al.* 2009). This, in turn, can have detrimental impacts on dependent fauna (Cahill *et al.* 2008). *Phytophthora cinnamomi* is usually identified in native plant communities by indicator species' deaths (Shearer *et al.* 2007). Its presence can be difficult to identify if indicator species are absent, or when disease expression has been obscured by fire (Utber, D 2011, pers. comm.). The pathogen is spread in infested soil by root-to-root contact, human and non-human vectors and by surface and subsurface water flows (Dunstan *et al.* 2008; Shearer *et al.* 2007).

There are ~ 60 species in the genus *Phytophthora*, and all of them are plant pathogens (Drenth & Guest 2004). In North America, the USDA Forest Service has invested nearly $30 million (USD) in research funding, and educational and management grants to assist with the control of *Phytophthora ramorum*, which is responsible for Sudden Oak Death in California and Oregon (Alexander & Lee 2010). In Europe, *Phytophthora alni*, which is responsible for dieback in alders, is continuing its spread, and is now considered to have reached epidemic levels in France and Bavaria (Jung *et al.* 2009). Introduced species like *Phytophthora cinnamomi* are considered the second greatest threat to biodiversity after habitat destruction (Simberloff *et al.* 2005). Efforts to manage introduced species are often constrained by lack of continuous funding (Simberloff *et al.* 2005). This has been the case in Australia, where management of *Phytophthora cinnamomi* has been hampered by limited public conservation investment (Cahill *et al.* 2008). To maximise benefits from public investment in biodiversity conservation, it is important to assess whether benefits from management of *Phytophthora cinnamomi* are likely to exceed costs. Not taking any action is likely to result in a high cost to society through the loss of biodiversity (Cahill *et al.* 2008). The net present value of biodiversity assets at risk from *Phytophthora* dieback have been estimated at ~ $1.64 billion (Hardy 2009). The same study also estimated that an investment of $58 million over seven years would be enough to reduce losses by $500 million (Hardy 2009). To date, little work has been undertaken in this research area, a lack which this investigation will begin to address.

The aim of this project was to assess the cost-effectiveness[1] of strategies proposed by the Park's managing authority, the Department of Environment and Conservation (DEC), to control *Phytophthora cinnamomi* in the FRNP. The results of this project will help DEC to protect the park's biodiversity in the most cost-effective manner. The results will also be of use in the management of *Phytophthora cinnamomi* in other national parks around Australia. The results will have further relevance for the management of *Phytophthora* species around the world by investigating the cost-effectiveness of eradication strategies compared to containment strategies.

This investigation was undertaken using the Investment Framework for Environmental Resources (Pannell *et al.* 2012). As part of the analysis, a benefit cost index (BCI) was calculated for two different *Phytophthora cinnamomi* management scenarios. The first scenario was based on the current proposed works and investment capacity of DEC, and the second was based on more comprehensive management works with increased investment needs. Inputs to the model were based on peer-reviewed literature, reports prepared by the park's managing authorities, and expert interviews. The outcome of this investigation is an assessment of the cost-effectiveness of both management strategies, and recommendations for further research needed to address major uncertainties in this field. The results could provide a strong business case for additional funding for the park managers.

2. Theoretical framework and model: INFFER

The Investment Framework for Environmental Resources (INFFER) is a tool to inform environmental investment decisions. The framework was designed to help natural resource management (NRM) bodies to plan projects to be internally consistent, and to deliver the most valuable environmental outcomes for the available resources. Analyses using INFFER prioritise projects based on benefit to cost ratios. The INFFER model was chosen for this investigation because it includes a comprehensive set of relevant variables that influence the cost-effectiveness of environmental projects. Factors considered within the assessment process include: asset value, which is based on environmental, economic and community considerations; the likelihood that private individuals will adopt changes proposed by a project; delays in the realisation of project benefits; and sources of uncertainty due to potential technical failure or socio-political risks. Further reasons to use INFFER include that it is consistent with economic theory, and strongly based on sound economic principles. INFFER can identify the projects with the highest benefit cost indices, and identify for each project the best policy mechanism to achieve desired changes in private land manager behaviour. As a framework, INFFER has been widely used in Australia and overseas, and is well documented (see www.inffer.org). Previous applications of INFFER include an assessment of potential changes in land-use and management to achieve nutrient reduction

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[1] In this investigation, the term cost-effective has been taken to indicate that benefits exceed costs.

targets in the Gippsland Lakes, and an investigation to identify improved priorities for land-use change in Victoria (Pannell *et al.* 2012; Roberts *et al.* 2009)

One of the main components of the INFFER framework is the calculation of a benefit cost index (BCI). The BCI presents the ratio of the benefits and the costs associated with a project. The BCI is generated through completion of the INFFER Project Assessment Form (PAF), which lays out the costs and benefits of different management scenarios. The formula for calculating the BCI is given below, and a more detailed explanation can be found in Pannell *et al.* 2012.

Equation 1. Calculation of benefit: cost index (BCI) used in INFFER (Pannell & Roberts 2009; Pannell *et al.* 2012)

$$\mathrm{BCI} = \frac{V \times W \times F \times A \times B \times P \times G \times DF_B(L) \times 20}{C + \mathrm{PV}(M)} \qquad (1)$$

where:

V = significance (or value) of the asset (score out of 100)

W = multiplier for proportional impact of works on asset value (0-1)

F = multiplier for technical feasibility risk (probability that the project will not fail due to problems with technical feasibility) (0-1)

A = multiplier for adoption of changed management by private landholders (proportion of adoption level required to achieve goal) (0-1)

B = multiplier for risk of adoption of adverse practices (probability that the project will not fail due to adverse adoption) (0-1)

P = probability that socio-political factors will not derail the project, and that required changes will occur in other institutions (0-1)

G = probability that essential funding subsequent to this project will be forthcoming (0-1)

DF_B = discount factor for benefits (proportion), depending on L

L = time lag until the majority of anticipated benefits from the project occur (0-100 years)

C = short-term cost of current project ($ million in total, over the three-to-five-year life of the project)

PV = present value function to convert future costs to equivalent present-day values

M = annual cost of maintaining outcomes ($ million per year, beyond the immediate project).

The numerator of equation (1) measures the net benefits of a project, adjusted for risk and time lags. The denominator represents the up-front costs of the project and all other costs, discounted to present day value, which are involved in maintaining the benefits of the project over a 20 year period. The BCI result is scaled according to the significance or value of the asset which is being considered. The INFFER model uses a relative scoring system to assign the value of V, where an asset value (V) of 100 has been calibrated to represent an asset of very high national significance (an example of which is the Gippsland Lakes (Roberts *et al.* 2009)). The BCI can be converted to a standard economic benefit cost ratio by using dollar values instead of this score. In this situation, V=100 is calibrated to equal $2 billion. The scalar, 20, is included in the calculation so that the threshold at which benefits is equal to costs is when BCI is equal to one. A BCI greater than one indicates that the benefits generated by a project will exceed the project costs.

2.1 Alternative approaches

There are many approaches to making conservation investment decisions. Marshall (2009) has conducted a review of the main methods which integrate economic accountability into the decision making process. He divides these into three broad areas: benefit cost analysis (BCA), multi-criteria analysis (MCA) and deliberative methods.

BCA is strongly rooted in neoclassical welfare economics in which it is assumed that individuals have fixed, known preferences with regards to goods and services; that the satisfaction of these preferences brings utility which is measurable in monetary amounts; and that this utility can be summed across individuals to describe ‘social welfare’ (Marshall *et al.* 2011). The aim of BCA is to determine whether (individual or collective) welfare improves as a result of a given project (Marshall *et al.* 2011). This welfare is measured by estimating all the benefits and costs arising from a given work or project. These benefits and costs are converted into present day value, which allows them to be compared as a ratio, regardless of the time scale in which they will occur. Where multiple projects are being assessed, the aim of BCA is to select the project which will maximise welfare. Notwithstanding its strong theoretical foundation, BCA is no longer widely used in Australian public decision making (Marshall *et al.* 2011). Possible reasons for this decline include concerns over assigning monetary values to environmental goods, and the ethical implications of summing utilities across individuals regardless of the existing level of wealth[2] (Roberts *et al.* 2009). Furthermore, most regional NRM bodies do not have the capacity to conduct an economically rigorous BCA (Marshall *et al.* 2011).

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[2] The summation of utilities in a BCA follows the concept of Pareto optimality, in which it is assumed that marginal increases in utility are similarly experienced across individuals, and that one person’s increase in utility can compensate for another’s decrease.

MCA describes an assortment of methods which base investment decisions on multiple criteria. MCA allows the inclusion of multiple strategies, multiple objectives, and different criteria with which to rank the achievement of those objectives, all of which can be considered simultaneously (Marshall *et al.* 2011). Its chief strength is in allowing decision makers flexibility within a structured decision making tool. However, MCA has been criticised for trying to combine measures which are fundamentally different, or incompatible, such as attempts to add hectares of remnant vegetation to tonnes of carbon dioxide emitted (Dobes & Bennett 2009). The process of weighting criteria can be complex, arbitrary and misunderstood by decision makers (Marshall *et al.* 2011). MCA can also be vulnerable to abuse by special-interest groups (Dobes & Bennett 2009). Some MCA methods may be very time demanding due to large information requirements from decision makers (Marshall *et al.* 2011).

Deliberative methods involve similar participatory decision making processes as MCA, where preferences are discussed and criteria are evaluated amongst stakeholders with varying views. However unlike MCA, deliberative method approaches do not use a formal model to calculate decision outcomes. Deliberative methods include small focus groups which may use techniques like brainstorming and citizens' juries (Rodríguez-Vargas 2011). Deliberative methods are likely to play a useful part in the process of making environmental investment decisions, but their effectiveness can be lessened by strategic manipulation on the part of stakeholders (Marshall *et al.* 2011). Group discussion can also fall down when there is insufficient interest on the part of participants, when there is a lack in understanding of key elements under debate, or when there is a lack of collective will to make hard decisions or equity trade-offs (Marshall *et al.* 2011).

Marshall (2009) describes INFFER's treatment of asset value (V) as being more practical and affordable than conventional BCA. However, when V is measured monetarily, the same problems involved with monetising environmental assets are incurred (Marshall *et al.* 2011). INFFER is thought to allow more deliberative methods to be included in the decision making process, although Marshall argues that use of the framework inevitably subjects the judgements of the decision makers to the values inherent in the model (Marshall *et al.* 2011). Nevertheless, INFFER is presented as a useful compromise between BCA and deliberative methods which has also found acceptance among governments and regional NRM bodies (Marshall *et al.* 2011).

3. Methods

Information used in the calculation of the INFFER BCI was collected from primary and secondary sources. Primary sources included interviews with staff members from DEC and other stakeholder groups. Secondary data sources included a review of the relevant literature to understand the epidemiology and current knowledge regarding *Phytophthora cinnamomi*, particularly of the work done in the south west of WA. Strategies which have been used to manage *Phytophthora cinnamomi* by other land managers were reviewed.

3.1 Study area – the Fitzgerald River National Park

The Fitzgerald River National Park is located between Albany and Esperance, on the south west coast of Western Australia (Figure 1). It is managed by DEC on behalf of the Conservation Commission, and there are three DEC rangers based in the park. The park is approximately 330,000 ha, making it one of the largest in Australia. In 1978, the park and adjacent areas were named a Biosphere Reserve due to extremely high floral diversity and high local community interest (Read 2009). The park receives roughly 40,000 visitors a year, and attracts significant revenue to the region through tourism and eco-tourism (DEC 2009, unpublished data). It is highly valued by visitors, both national and international, and by the local community (Read 2009). Attractions of the park include its high floral diversity, marine recreational activities, hiking and whale watching. The park satisfies a growing demand for tourism activities that provide high-value natural landscapes with public access (DEC 2009, unpublished data).

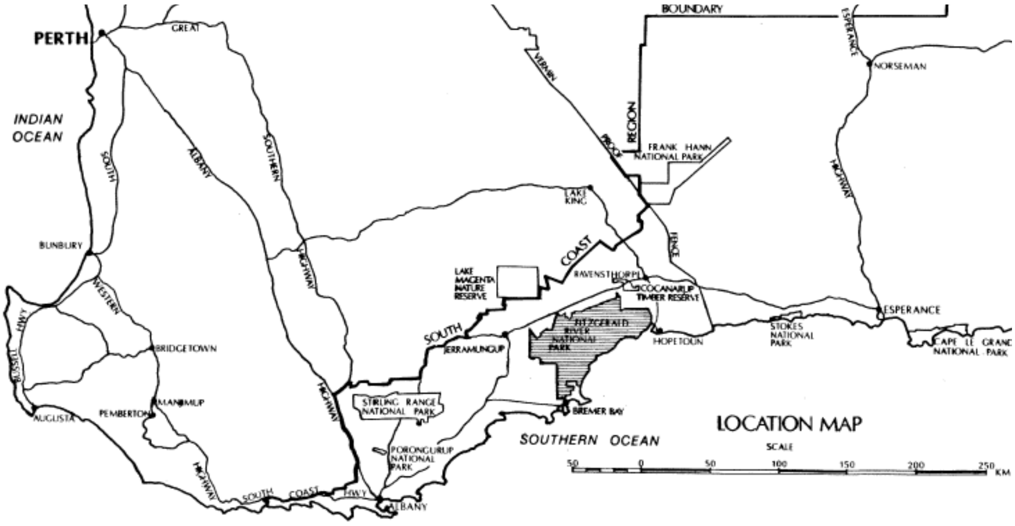

Figure 1. Fitzgerald River National Park (shaded) in the Southwest of Western Australia (Moore *et al.* 1991).

Currently, less than 1% of the area of the park is infested with *Phytophthora cinnamomi* (Dunne *et al.* 2011). However, the moist climate, clay soils and rich variety of susceptible host species in the park are very favourable for *Phytophthora cinnamomi* development (Moore *et al.* 1991). There are three main sites of *Phytophthora cinnamomi* infestation in the park. These are the Bell Track infestation, the Pabelup Drive infestation and the Susetta River infestation (Figure 2). All of the infestations occurred during maintenance or other works, and were not directly caused by recreational park visitors (Lullfitz, A 2011, pers. comm.). The first known infestation in the park occurred during the unauthorized construction of Bell Track in 1971 (Dunne *et al.* 2011). This infestation now covers 212 ha and is the largest infestation in the park (Dunne *et al.* 2011). Pabelup Drive includes two infestations, which together comprise approximately 71 ha (Dunne *et al.* 2011). Both infestations at Pabelup Drive are believed to have originated during the construction of fire breaks during a wildfire in 2003 (CPSM 2009). The infestation at Susetta River is the smallest of the three infestations and is believed to have originated from the spread of infested gravel from one of two gravel pits which are close to the park (Read 2009). This infestation extends 5 km along the Susetta River.

To date, DEC has employed various management strategies to contain these infestations. These have included: fencing of the infested sites to prevent animals acting as disease vectors; phosphite and herbicide application; and hydrological engineering works (Dunne *et al.* 2011). The engineering works are considered innovative and experimental, and have contained the Bell Track and the Pabelup Drive infestations to their respective catchments (Schoch 2008). Other possible approaches to managing *Phytophthora cinnamomi* rely on hygiene measures and quarantine of the infected area (Podger 1999).

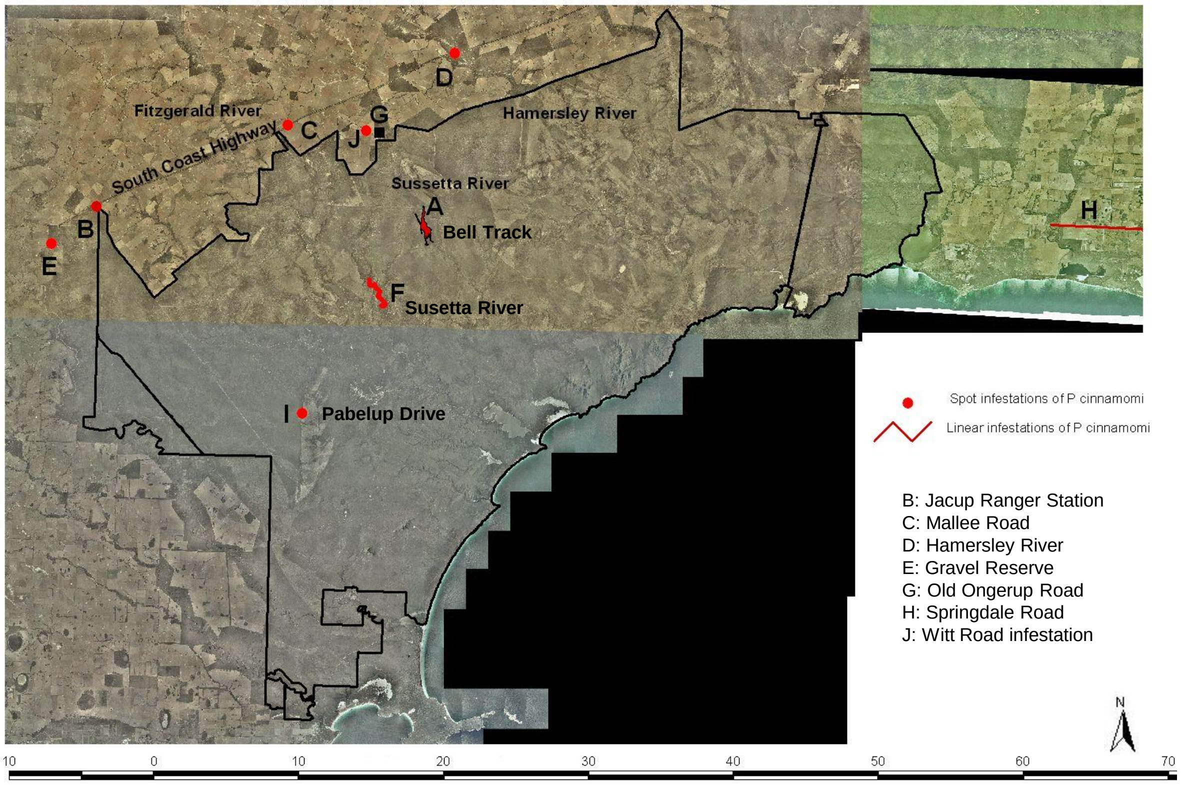

Figure 2. *Phytophthora cinnamomi* occurrences within and surrounding FRNP (DEC 2009, unpublished data).

3.2 Expert consultation

3.2.1 Albany visit

A visit to the park was made to examine the dieback information available to park visitors, and to speak with park rangers. Meetings were conducted with staff from South Coast Natural Resource Management and DEC Albany office to discuss current management efforts by those organisations, and to determine their views of the threat posed by *Phytophthora cinnamomi*. Further strategies that could be undertaken to manage or eradicate the pathogen from the park were discussed.

3.2.2 Securing support from the Department of Environment and Conservation

To secure support for the project it was necessary to brief DEC managers regarding the scope of the investigation, and its likely ramifications, before further cooperation could be authorised. Once this was given, further meetings were conducted with staff from the DEC Science Division and DEC Albany office. Several reports detailing previous containment works in the park, as well as information for the current analysis were made available.

4. Results

4.1 Developing management scenarios

During the meetings, two scenarios for the management of *Phytophthora cinnamomi* in the FRNP were investigated and discussed. Each scenario involved different management works, with correspondingly different up-front and maintenance costs, risks and benefits. The time frame for both management scenarios was set at 20 years. This allowed sufficient time for high intensity but low frequency weather events to test previous containment works in the park. Scenario A was based on the current management works that DEC plan to employ (Table 1). The management goal for this scenario was the containment of current infestations, and the prevention of any further infestations. Scenario B involved a larger-scale response to *Phytophthora cinnamomi* (Table 1). This response included eradication of current infestations, fencing of the park and a greater management presence at park entrances. Several unofficial entrances would be closed, reducing the number of park entrances to four. These measures would allow stricter hygiene procedures to be enforced upon entry into the FRNP. This would reduce the potential for human vectoring of the pathogen by improving hygiene compliance from recreational visitors to the park. Both scenarios were discussed with DEC to ensure completeness and reliability of estimates. It should be noted that previous works undertaken to manage *Phytophthora cinnamomi* in the FRNP are still being monitored and the results verified.

Table 1. Proposed works to address *Phytophthora cinnamomi* in the FRNP under two management scenarios.

	Management works
Scenario A	Monitoring of previous containment strategies
	Installation of additional surface geo-textile membrances at Bell Track infestation
	Develop fumigation techniques for spot eradication at Bell Track and Pabelup Drive infestations
	Survey and interpretation program
	Upgrades to infrastructure, including high security gates
	Assess the effectiveness of DEC's current hygiene practices
	Phosphite application
	Maintenance of existing infrastructure
Scenario B	Limit park entrances to four (option to close the two northern park entrances if weather conditions are considered conducive to pathogen spread)
	Entrances to be manned by park rangers
	Every vehicle inspected/cleaned on entry: four automatic car-wash systems for public use at park entrances
	Educational material on dieback at all four park entrances
	Fence park in its entirety
	Eradication of existing infestations see Dunne *et al*. (2011)

4.2 Parameter values

The ten parameter values for the INFFER BCI model (see Equation 1), for the management scenarios A & B, were estimated by two DEC staff members with experience and expert knowledge of *Phytophthora cinnamomi* and the FRNP. The base-case values for both scenarios were decided upon in conference with David Pannell, the developer of the INFFER framework, in order to ensure that responses were consistent with the intended meanings of questions, and appeared reasonable in the light of responses used in previous applications of the framework (Table 2).

(1) The value for the park was set at V=40 for both management scenarios. This was based on the INFFER 'Guide to scoring V for different types of assets' (www.inffer.org), which identifies the FRNP as of 'very high state significance', with a V in the range of 25 to 40. The score was set at the upper limit of this range in consideration of the park's international biosphere reserve status. Another factor which influenced this decision was the prominence of the FRNP as the largest park in the South-West Botanical Province that offers visitors an environmental setting largely unaffected by plant deaths caused by *Phytophthora cinnamomi*. Using the INFFER guideline that each point represents $20 million, the base-case value for the park (V=40) represents $800 million.

(2) & (3) The estimates by the DEC staff members differed substantially for two parameters. The first of these was impact of works (W), which captures the change in asset value with and without the planned project works, and the second was for long-term funding (G), which reflects the probability that long-term funding will be obtained. In the first instance, the more cautious estimate was chosen for both management scenarios (Table 2). In the second instance, G was determined by averaging the estimated values from both DEC staff members

(*G*=0.1 and *G*=0.9). This gave a value of *G*=0.5 for management scenario A. The larger scale of management works in scenario B is likely to decrease the need for high levels of future funding, and so *G* was set at 0.7 in scenario B.

(4) The estimates of technical feasibility (*F*) for both scenarios were similar for both DEC staff members (Table 2).

(5) The probability of the project not failing due to socio-political risk (*P*) was unanimously estimated at 0.97 by both of the DEC staff. This assessment was accepted in light of the fact that management of *Phytophthora cinnamomi* is not a contentious issue and is unlikely to become one in the future.

(6) The value for time lag (*L*) was established at 10 years to allow for patterns of infestation similar to those which have previously been observed in the park. This observation was at the second Pabelup infestation, where the lag between infestation and discovery is estimated to be 5 - 10 years (Dunne C 2011, unpublished data).

(7) Up-front costs for management scenario A were taken from a Specific Nature Conservation Project proposal for the 'Prevention, Containment and Eradication of *Phytophthora cinnamomi* (*Phytophthora* dieback) infestations in the National Parks of the South Coast of Western Australia' 2011/12 (Table 2). Costs for scenario B were estimated by one of the DEC staff members.

(8) The maintenance costs (*M*) of scenario A were doubled from $200,000 to $400,000 to allow for management works to contain up to three potential infestations that may be discovered in the monitoring survey, or through subsequent surveys over the next 20 years. Costs for management scenario B were based on estimates by DEC staff.

(9) Adoption (*A*) for both scenarios was determined after conversations with the dieback officer at SCNRM, who has directed that organisation's dieback education campaign and worked extensively with the local shires and communities in dieback awareness. This officer predicted that if adequate hygiene infrastructure were provided at the FRNP, then the majority of park visitors would be likely to comply with hygiene requirements (Lullfitz, A 2011, pers. comm.). However, non-adoption by even a few individuals might have a disproportionate effect if even one of those individuals is carrying the pathogen on their shoes or on their car. For this reason, adoption was established at a lower range (Table 2).

(10) The parameter for adverse adoption (*B*) did not apply to either management scenarios, so it was set to 1, which negates its effect in the multiplicative BCI equation.

Table 2. Base-case parameter values for scenarios A & B that were used to calculate benefit cost indices using the INFFER investment framework.

Management Scenario	**Value (V)**	**Impact of works (W)**	**Technical feasibility (F)**	**Adoption (A)**	**Socio-political risks (P)**	**Long-term funding (G)**	**Lag (L)**	**Up-front cost (C)**	**Maintenance cost (M)**
	1-100	0-1	0-1	0-1	0-1	0-1	0-100 years	$ million	$ million/year
A	40	0.1	0.82	0.7	0.97	0.5	10	0.24	0.4
B	40	0.17	0.82	0.7	0.97	0.7	10	5	0.25

4.3 Benefit cost analysis

Based on the analyses described above, benefit cost indices (BCI) were calculated for each management scenario to indicate their cost-effectiveness. The BCI scores for both management scenarios are greater than one (Table 3). In scenario A, the ratio of benefits to costs is three to one (BCI=3.0). In scenario B, the ratio of benefits to costs is roughly four to one (BCI=4.2).

Although the present value of maintenance costs in scenario B is $1.6 million less than for scenario A, the total costs' present value of scenario B is $3.16 million greater than the costs of scenario A (Table 3). This is a result of the substantially greater up-front costs in scenario B, which offset the savings from lower maintenance costs.

If no management works are undertaken in the park, it is estimated that the value of the park will decrease by 20% over the next 20 years, through new infestations and further spread of current infestations. Works from scenario A could reduce this damage to 10% (Table 2). This reduction will be achieved at a total cost (present value) of $4.52 million (Table 3). This cost is ~77% greater than total state government expenditure that has been invested in *Phytophthora cinnamomi* management in the park since 2006, through Specific Nature Conservation Project grants.

The works undertaken in scenario B are estimated to reduce damages to the park to 3% (Table 2). This will be through eradication of existing infestations and prevention of any further infestations, at a present value cost of $7.68 million (Table 3).

Table 3. Results from the INFFER benefit cost index (BCI)† analysis for management scenarios A & B.

Management Scenario	Present value of maintenace costs‡ $ million	Present value of total costs $ million	Benefit: Cost Index
A	4.28	4.52	3.0
B	2.68	7.68	4.2

†A BCI > 1 indicates that project benefits are greater than costs.
‡Maintenance costs will be spread over the period of 20 years.

4.4 Sensitivity analysis

A sensitivity analysis of model parameters was conducted to determine the robustness of the results. Each parameter was varied across an uncertainty range, based on the magnitude of the discrepancy between the estimates of the two DEC staff, or as considered appropriate based on previous applications of INFFER (Pannell, D 2011, pers. comm.). The ranges in parameter values which were examined are shown in Table 4. The greatest discrepancy in expert estimates was considered for the low and high values of impact of works (*W* – between 0.03 and 0.3 in scenario A and between 0.03 and 0.39 in scenario B). Other large uncertainties were considered in the probability of obtaining long-term funding (*G*) and lag time (*L*), the ranges of which differ by factors of nine and three respectively, in both scenarios.

Table 4. Parameter ranges considered in sensitivity analysis of parameter inputs for management scenarios A & B.

		Management Scenario A			Management Scenario B		
Parameter	**Possible values**	**Low**	**Base-case**	**High**	**Low**	**Base-case**	**High**
Value (V)	1-100	25	40	50	25	40	50
Impact of works (W)	0-1	0.03	0.1	0.3	0.03	0.17	0.39
Technical feasibility (F)	0-1	0.4	0.82	0.87	0.4	0.82	0.87
Adoption (A)	0-1	0.5	0.7	0.9	0.5	0.7	0.9
Socio-political risks (P)	0-1	0.85	0.97	1	0.85	0.97	1
Long-term funding (G)	0-1	0.1	0.5	0.9	0.5	0.7	0.9
Lag (L)	0-100 years	5	10	15	5	10	15
Maintenance cost (M)	$ million/year	0.25	0.4	0.55	0.1	0.25	0.4

In Table 5, parameters are ranked by the absolute difference between the BCI estimated at the lowest and highest value of the given parameter. The greatest difference was observed between the high and low BCI values for impact of works (scenario A=8.2 and scenario B=9.0). In scenario A, the next greatest difference was observed for the probability of receiving long-term funding (*G*) and maintenance costs (*M*). In scenario B, large BCI differences were found for the value (*V*) and technical feasibility (*F*) parameter values. In both scenarios, the BCI was least sensitive to changes in the socio-political risk parameter (*P*). A noteworthy result of the sensitivity analysis is that BCIs of less than one (implying that the project offers low value for money) were observed for low impacts of works in both scenarios, and for low probability of obtaining long-term funding in scenario A. This implies that if the lower estimates of impact of works and probability of obtaining long-term funding are indeed correct, then the benefits of *Phytophthora cinnamomi* management, as they pertain to the two scenarios, may not justify the costs.

Table 5. Sensitivity analysis of management scenarios A & B, where a change in only one parameter was considered at a time. BCI results are given for the low and high value of the parameter that was changed. Scenarios are ordered by increasing absolute difference between the high and low BCI values.

Scenario A				**Scenario B**			
	BCI		**Absolute difference**		**BCI**		**Absolute difference**
Variable changed	**Low**	**High**		**Variable changed**	**Low**	**High**	
Base-case scenario	3.02			Base-case scenario	4.24		
Socio-political risk (P)	2.7	3.1	0.5	Socio-political risk (P)	3.7	4.4	0.7
Lag (L)	3.9	2.4	1.5	Maintenance cost (M)	5.4	3.5	1.9
Adoption (A)	2.2	3.9	1.7	Lag (L)	5.4	3.3	2.1
Technical feasibility (F)	1.5	3.2	1.7	Adoption (A)	3.0	5.5	2.4
Value (V)	1.9	3.8	1.9	Long-term funding (G)	3.0	5.5	2.4
Maintenance cost (M)	4.7	2.2	2.5	Technical feasibility (F)	2.1	4.5	2.4
Long-term funding (G)	0.6	5.4	4.8	Value (V)	2.6	5.3	2.6
Impact of works (W)	0.9	9.1	8.2	Impact of works (W)	0.7	9.7	9.0
Column average	2.3	4.1			3.3	5.2	
Total average	3.2				4.2		

A further sensitivity analysis was conducted on the three variables from both management scenarios which, when varied, produced the greatest absolute change in the BCI relative to the base-case: impact of works (*W*), probability of receiving long-term funding (*G*) and asset value (*A*) (Table 5). Three possible parameter values were considered for each of these variables: low, base-case and high (see Table 4). All other parameters in the model were maintained at their base-case values. Every possible combination of parameter values was analysed, leading to a total of 27 possible combinations for each management scenario (3 x 3 x 3). The purpose of this analysis was to examine the likelihood of there being a BCI below one when combinations of parameter changes occur.

Eight out of all possible combinations of parameter values returned a BCI less than one (Table 6). In scenario A, the BCI was less than one when impact of works was low, and the probability of long-term funding was either low or base-case. The BCI was also less than one for all combinations where impact of works was base-case, and probability of long-term funding was low. In scenario B, the BCI was less than one for eight out of nine combinations where impact of works was low, irrespective of the probability of long-term funding or asset value. The results of the sensitivity analysis in Table 6 indicate that, based on the overall average of all possible BCIs, the BCI of management scenario A is still less than that for scenario B (with average BCIs of 4.2 and 4.7 for the respective scenarios).

Table 6. Benefit cost indices for every combination of low, base, and high parameter values in both management scenario A and management scenario B.

Management scenario A[†]					**Management scenario B[‡]**				
Impact of works (W)	**Long-term funding** (G)	**Asset value** (V)			**Impact of works** (W)	**Long-term funding** (G)	**Asset value** (V)		
		Low	Base-case	High			Low	Base-case	High
Low	Low	0.11	0.18	0.23	Low	Low	0.33	0.53	0.67
	Base-case	0.57	0.91	1.1		Base-case	0.47	0.75	0.94
	High	1.0	1.6	2.0		High	0.60	0.96	1.2
Base-case	Low	0.38	0.60	0.76	Base-case	Low	1.9	3.0	3.8
	Base-case	1.9	3.0	3.8		Base-case	2.6	4.2	5.3
	High	3.4	5.4	6.8		High	3.4	5.5	6.8
High	Low	1.1	1.8	2.3	High	Low	4.3	6.9	8.7
	Base-case	5.7	9.1	11		Base-case	6.1	9.7	12
	High	10	16	20		High	7.8	13	16
Column average		2.7	4.3	5.4			3.1	4.9	6.1
Total average			4.2					4.7	

[†] **Scenario A parameter values (low, base-case and high): impact of works - 0.03, 0.1, 0.3; long-term funding - 0.1, 0.5, 0.9; asset value – 25, 40, 50.**

[‡] **Scenario B parameter values (low, base-case and high): impact of works - 0.03, 0.17, 0.39; long-term funding - 0.5, 0.7, 0.9; asset value – 25, 40, 50.**

5. Discussion & conclusion

The results of this analysis support the investment of public conservation funds to control *Phytophthora cinnamomi* in the FRNP, as both management scenarios result in significantly greater benefits than costs under most scenarios examined (BCI > 1, see Tables 3 and 6). This result is based on the integration of information provided by various experts and stakeholders who were consulted during the project, combined with information from existing technical research. Management scenario A represented the current management strategies proposed by DEC to manage *Phytophthora cinnamomi*. This scenario was based on works planned for the period 2011/2012, through a Specific Nature Conservation Project. Even though the estimated impact of the proposed works is low, benefits would still exceed costs due to the low level of investment that is required to undertake management works. Management scenario B represented a more costly strategy which would eradicate the three currently identified infestations in the park. This strategy would decrease the probability of future infestations through greater access controls including: a fence around the park; reducing the park entrances to four; ranger presence on all four entrances to ensure hygiene compliance by park visitors; and the provision of car washes and other hygiene infrastructure for public use at park entrances and at the start of walking trails within the park. Investment in management scenario B would also reduce the significant risk of current infestations spreading into other areas in the park, through eradication of these sites.

Scenario B represents an investment with a higher benefit to cost ratio than scenario A. The extra investment required to fund scenario B is $3.16 million, which includes the present value of all on-going maintenance costs for the subsequent 20 year period. The higher costs in scenario B would fund works which are estimated to decrease damage to the park by an extra 7% compared with scenario A. If funding to meet the higher up-front costs could be obtained, then it is likely that the returns to investment would be greater than in scenario A. These results suggest that a larger initial investment to manage *Phytophthora cinnamomi* in the park could be more efficient. Scenario B has lower maintenance funding needs (M), and the likelihood of obtaining ongoing funding (G) was estimated as 40% higher than in scenario A. This estimation of G was based on the view that a higher initial investment would decrease the park managers' requirement and reliance on subsequent funding. The eradication of the existing infestations would remove the need to maintain containment works, and the probability of new infestations occurring would be minimized through the infrastructure that would be funded in this scenario. This would decrease the likelihood that funding to manage new infestations would need to be found.

Eradication of *Phytophthora cinnamomi* would be the 'ideal outcome,' according to the national Threat Abatement Plan for *Phytophthora* dieback (DEH 2002, p. 6). This is because it implies that no further resources would be required to manage the infestation sites. However, eradication techniques for *Phytophthora cinnamomi* are still relatively new (Dunne *et al.* (2011), Dunstan *et al.* (2010)). Given that the works that would be undertaken in scenario B would involve eradication on a larger scale than has previously been achieved in Australia, there are risks involved with regards to the technical feasibility and uncertainties about the impacts of works in this scenario. On the other hand, the eradication works in scenario B would represent a significant opportunity to increase the knowledge and capacity of park managers to deal with the pathogen not only in the FRNP but around Australia. If eradication was successful, it could attract increased funding for *Phytophthora cinnamomi* management. It would also help to dispel the current consensus that problems posed by *Phytophthora cinnamomi* are so wide-spread, that they are not worth the cost of control (Cahill *et al.* 2008). This study has shown that, provided that experts' assumptions are correct, there is a prospect for cost-effective eradication of *Phytophthora cinnamomi* from the FRNP.

The models of both management scenarios are sensitive to variation in the parameter estimates. Individual changes in parameter values revealed two situations in scenario A and one situation in scenario B where the BCI was less than one. A sensitivity analysis which examined simultaneous changes in three parameter values (impact of works (*W*), probability of obtaining long-term funding (*G*), and asset value (*V*)) returned a further eight out of the possible 27 scenario combinations where BCI was less than one in scenario A and in scenario B. The trend in both scenarios was that BCI was less than one when impact of works was low. Nevertheless, even when all the uncertainties in the estimation of the BCIs for both scenarios are considered, the analysis still supports the conclusion to invest in controlling *Phytophthora cinnamomi* in the FRNP. The results from the sensitivity analysis also support preferential investment in scenario B over scenario A (average BCI scenario B > scenario A, see Tables 5&6).

The cost-effectiveness of both management scenarios was most sensitive to the estimation of impact from management works (W). When the values estimated for *W* were significantly lower (70% and 80% in scenarios A & B respectively) than in the base-case, and all other variables were unchanged, the benefits achieved (measured as damage to the park that would not occur) did not justify the costs. Both of the DEC staff members consulted on this investigation thought that the possibility of this occurring (*F*) was less than 20%.

The cost-effectiveness of management scenario A was also sensitive to the probability of obtaining long-term funding. When this was considered unlikely (probability=0.1%), and all other parameters left unchanged, then BCI was less than one. This result would reflect the inability of the park managers to maintain crucial access and hygiene infrastructure. This is an extreme scenario, but one which could occur if there was a comprehensive change in public conservation funding priorities over the next 20 years, and no money was made available for management of *Phytophthora cinnamomi* in the FRNP. This scenario seems unlikely, given the large threat that the pathogen poses to biodiversity in the south west of Australia, and in light of the federal government's commitment to 'promote the conservation of biodiversity' through the Environment Protection Biodiversity Conservation Act 1999 (Commonwealth of Australia 1999, p.1).

Uncertainties regarding asset value did not produce significant changes in the model results for either scenario, when considered in isolation from other parameter changes. When questioned on the asset value of the park, both DEC staff members were inclined to place the value at the top end of the scale (i.e. very high national or international significance). While the environmental value of the park may be sensitive to its level of infestation by *Phytophthora cinnamomi*, the community portion of this measure is probably not as sensitive (Dunne, C 2011, pers. comm.). If this value changed at all as a result of *Phytophthora cinnamomi* infestation, it would most likely be very gradual and with a significant delay compared to the actual level of damage from infestation. This has been the case in the Stirling Ranges National Park (SRNP). In 1997-98, visitor numbers to the SRNP were 90,000, double that currently received at the FRNP, even though roughly half of SRNP was infested with *Phytophthora cinnamomi* at the time (Herford *et al.* 1999).

There are limited studies that compare the cost-effectiveness of management activities that prevent the establishment of *Phytophthora cinnamomi* with containment or eradication action. The high costs associated with eradication or with managing established populations (Goheen 2009), could likely be avoided by directing more funding towards preventive measures (Pimentel *et al.* 2001; Simberloff *et al.* 2005). In the FRNP, Dunne (2011, unpublished data) found that the *Phytophthora cinnamomi* infestation at Pabelup Drive could have been avoided by adhering to strict hygiene controls at an estimated cost of $1,000, whereas containment at this site has cost 400 times this amount and will require ongoing maintenance.

Future events are likely to change management conditions and threat assessment of *Phytophthora cinnamomi* in the FRNP. The FRNP Improvement Scheme, an initiative by the State and Federal Governments to enhance tourist access and facilities in the park, will likely lead to an increase in visitor numbers. This has the potential to increase human vectoring of *Phytophthora cinnamomi*, as public access is associated with much greater overall infection by the pathogen (Donovan 2006). Changing climate conditions will also affect the success of pathogen spread rates, as *Phytophthora cinnamomi* is very reliant on moist and warm conditions (Cahill *et al.* 2008; Shearer *et al.* 2009). Increases in rainfall and temperature will likely increase the pathogen's range into new areas, while decreases are likely to result in a shrinking of the pathogen's range or a decrease in its virulence (Cahill *et al.* 2008). The costs of containment and eradication could potentially decrease through further scientific inquiry into the epidemiology of *Phytophthora cinnamomi*, and as the efficacy of management actions is improved. The possibility that more cost-effective measures will be developed in the future provides an additional motivation to at least contain *Phytophthora cinnamomi* in the short term, so that the benefits of cheaper management can be exploited in the future. If the pathogen is allowed to spread over large areas, the scale of infestations may prohibit cost-effectiveness, even at lower future control costs[3].

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[3] In economic terms; the 'option value' of inaction may be disproportionately high.

This investigation has focused attention on the variables that need to be measured to enable management decisions to be made. The key uncertainties in the model identify priorities for further research, and management/structural changes which are needed to accurately determine the cost-effectiveness of management strategies to address *Phytophthora cinnamomi*. These include the need for better biophysical data to quantify the impact of management works. The results also reveal how reliance on uncertain funding environments prevents confidence in the accomplishment of project goals, through an inability to assure the future maintenance and upkeep of management works. The estimates of the parameters for this investigation were based on 'best available knowledge' as judged by park management and research staff, together with judgements made by the researcher based on published research. In conservation programme planning, relying on the experience of managing staff is considered quite common (Guikema & Milke 1999). When making conservation investment decisions, NRM managers often face major information gaps, or lack relevant expertise or the resources necessary to incorporate pertinent economic, social and biophysical data (Seymour *et al.* 2008). In particular, Murdoch *et al.* (2007) have remarked that estimates of conservation benefits are often based on educated guesses. The use of an investment decision tool like INFFER makes this process transparent, allowing estimations to be scrutinised.

The importance or validity of using a rigorous decision model when there is uncertainty regarding conservation benefits has been mentioned by Pannell (2009) and Murdoch *et. al.* (2007). Pannell (2009), in particular, conducted extensive simulations of hypothetical prioritisation decisions, and concluded that the rigour of the economic model used to assess investment decisions can be more important than the accuracy of the estimation of the variables. This finding supports the conclusions which have been drawn from this investigation, given that many of the costs associated with the management strategies in scenario B had to be estimated. The returns presented are the most rigorous that could be delivered with the current state of knowledge. They should, however, be updated when new knowledge becomes available. A key management work included in scenario A is a study into the efficacy of existing DEC hygiene measures. The results from this work will allow technical feasibility to be estimated with greater confidence. The conclusions presented in this investigation should be updated when this new data becomes available.

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