COST-BENEFIT ANALYSIS OF BIOSECURITY AND FOREST HEALTH RESEARCH

J. A. TURNER, L. S. BULMAN, B. RICHARDSON, and J. R. MOORE
New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

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ABSTRACT

Estimates of the economic benefit of biosecurity and forest health research to the New Zealand forest-growing industry and urban forest estate were made using cost-benefit analysis. The cost associated with the arrival of exotic forest pests was the sum of costs of eradication and control programmes, reduced harvest value, household expenditures to control the exotic pest, and replacement of affected trees in the urban forest. The expected cost associated with each of these was dependent on the likelihood of pest arrival, detection, eradication, and successful control, and the effect of research on these. Depending on the assumed efficacy of the research, the net present benefit of the $3.5 million annual research cost ranged from $3,519 million to $5,888 million, so there is considerable benefit to the New Zealand forest-growing industry and urban forest estate from biosecurity and forest health research. Sensitivity analysis showed benefits of research to be most sensitive to the estimate of the value of the urban forest estate.

Keywords: cost-benefit analysis; economic value; exotic forest pests; forest health; biosecurity; research.

INTRODUCTION

The forest industry is an important contributor to the New Zealand economy, accounting for 3.4% of New Zealand's gross domestic product in 2003–04. The industry employed 26 576 persons in forestry, logging, and first-stage processing in 2003 (New Zealand Forest Owners' Association 2004). Forest product exports were worth $3,710 million in 2003, accounting for 12.7% of all exports by value (New Zealand Forest Owners' Association 2004).

The New Zealand forest industry is based on highly productive plantation forests, producing 18 to 24 m^3/ha annually (Brown 2000). As at 1 April 2003 there were 1.83 million ha of plantation forest, 89% of which were planted in *Pinus radiata* D.Don (Ministry of Agriculture and Forestry 2004). New Zealand's industrial roundwood harvests were 22.4 million m^3 to year-end 31 March 2003 (New Zealand Forest Owners' Association 2004). This represents 1.42% of the world's total harvests (Food and Agriculture Organisation 2004) from 0.05% of the global forest resource (New Zealand Forest Owners' Association 2004). New Zealand's potential harvest is predicted to grow to between 33.6 and 39.8

million m^3 in 2021–25, based on assumed new land planting rates of zero and 20 000 ha/year, respectively (Ministry of Agriculture and Forestry 2000).

The introduction of exotic forest pests is a significant threat to the productivity of New Zealand's plantation forests. There are more than 400 pests affecting *P. radiata* that are not presently found in New Zealand (Flux *et al.* 1993). Threats include western gall rust caused by *Endocronartium harknessii* (J.P.Moore) Y.Hirats., root disease fungi such as *Phellinus weirii* (Murrill) R.Gilbertson and *Heterobasidion annosum* (Fr.) Bref. sensu stricto, and bark beetles such as the North American *Ips grandicollis* (Eichhoff) and mountain pine beetle *Dendroctonus ponderosae* Hopkins. The pine shoot moth (*Rhyacionia buoliana* Denis & Schiffermüller) is an insect threat that can kill pine seedlings and affect growth and form of pines (J. Bain, Forest Research, pers. comm.).

The growth in global trade is creating increased opportunities for unintentional introductions (Pimentel *et al.* 2000; Tkacz 2002). New Zealand import volumes have grown 6.8%/year over the last decade (Statistics New Zealand 2004a), and Forest Research unpublished data show over 250 exotic forest pests have established in New Zealand since the 1950s (Bain, pers. comm.).

Given the value of the forest industry to New Zealand's economic wellbeing, and the threat posed by exotic forest pests, an active biosecurity and forest health research programme is viewed by the New Zealand forest industry as an important means of ensuring its continued contribution to the economy (Self 2003).

In this paper, the economic benefit to the New Zealand forest-growing industry and urban forest estate of continued biosecurity and forest health research is estimated, using cost-benefit analysis. The remainder of this section reviews previous estimates of the costs of exotic forest pests to the forest sector, and the methods used to make these estimates. Subsequent sections present the structure and assumptions of the cost-benefit analysis, and results and conclusions from the study.

Cost-benefit Analysis of Exotic Forest Pests

The main benefit of biosecurity and forest health research is a reduction in the economic losses associated with the establishment of exotic forest pests. Estimation of these losses has used a mix of three methods — forest sector market models, growth and yield models, and cost-benefit analysis. Studies using forest sector market models analyse the impact of pests in a demand-supply context (Kuchler & Duffy 1984; Holmes 1991; USDA Forest Service 1991). The supply function for wood is shifted to the left to reflect the impact of pests on supply. There are several advantages to this method. Firstly, it captures price adjustments due to reduced supply, allowing consideration of the effect of changes in the growing sector on land use and the processing sector. Secondly, producer and consumer surplus effects are directly estimated, with the net present value of these being a measure of the economic impact (USDA Forest Service 1991).

Stand growth and yield models are used to simulate the impact of forest pests on product yields (Geron & Hafley 1988; Cubbage *et al.* 2000). Stand level impacts are aggregated to estimate regional impacts using information on region-wide frequency of species, site quality, and infection rates (Cubbage *et al.* 2000). This method enables assessment of the impact of pests on optimal forest management and the mix of products harvested.

Cost-benefit analysis (Boardman *et al.* 2001) is the most widely used method of estimating the economic impact of exotic forest pests (Rose 1983; USDA Forest Service 1991). Estimates from cost-benefit analysis vary widely (Table 1) because of differences in the costs and benefits included, and how an economic value is placed on these. USDA Forest Service (1991, Chapter 5), in a risk assessment of pests associated with imports of larch logs from the Soviet Far East, calculated economic costs due to declines in growth and increases in mortality. These costs were estimated using cost-benefit analysis and forest sector market models; hence they included the effect of changes in stumpage prices. Potential economic losses arising from growth loses due to insect defoliators were estimated to be US$35,050 million to US$58,410 million from 1990 to 2040 (for a 4% discount rate). Pimentel *et al.* (2000), using an estimated annual loss of US$7 billion of forest products production due to plant pathogens (US Bureau of the Census 1998), estimated that these pathogens cost the United States US$2,100 million/year (US$45,113 million over 50 years at a 4% discount rate).

The study presented in this paper uses cost-benefit analysis for several reasons. Firstly, the supply and demand relations needed for a market model have not been estimated for the New Zealand forest sector. Secondly, New Zealand is a small open economy; therefore prices in the sector are set internationally, with changes in New Zealand wood supply having little effect on the world price of wood. Finally, New Zealand exports 36% of its harvest as logs (New Zealand Forest Owners' Association 2004), and so the wood supply may be significantly reduced before supply to domestic processors is affected.

Carter (1989) quantified the *ex ante** impact of potential exotic forest pest introductions on the New Zealand forest industry. He used estimates of economic losses in the national exotic forest estate due to an established high-impact pest (*Dothistroma pini* Hulbary $5.40/ha annually), and a low-impact pest (*Diplodia pinea* (Desm.) Kickx $0.10/ha annually), and the expected number of introductions per annum in each impact class affecting *P. radiata* and species other than *P. radiata*. These per-hectare losses were scaled up by the area of national exotic forest to calculate the total expected loss over 30 years. Carter (1989) also estimated the costs and benefits of eradication and control for a range of rates of detection of new introductions. Eradication was assumed to cost $700,000 per eradication and was attempted for the 53% of expected introductions that would be eradicable. The benefit of eradication was 100% of the expected value loss. Control costs were assumed to be $1/ha annually across the entire exotic forest estate, with the benefit of control being 50% of the expected annual value loss. The estimated net benefit of reduced eradication and control costs (at an unspecified discount rate) for a 50% detection rate was $4.5 million, and $8.5 million for a 95% detection rate (Carter 1989, Table 8).

Sweet (1989), New (1989), and Bulman (unpubl. data) have quantified the *ex post** economic impact of forest pathogens in New Zealand based on estimates of the proportion of forest estate affected, the percentage reduction in volume increment due to the pests, and the costs of control. Sweet (1989) estimated an annual cost of $21.8 million. This estimate included the direct costs of the forest health programme (surveillance, research and diagnostic work, quarantine costs), Dothistroma needle-blight control costs, and yield

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* *ex ante* – refers to values that are calculated before uncertainties are resolved
ex post – refers to values that are calculated after uncertainties are resolved

TABLE 1–Estimates of economic costs of exotic forest pests*.

Cost	Cost estimate ($ 10^6)†	Pest	Country/ Region	Year/ Period
Eradication	NZ$10	*Orgyia thyellina*[1]	New Zealand	1997
	NZ$100	*Teia anatoides*[2]	New Zealand	2003–
	NZ$3.98	*Ophiostoma novo-ulmi*[2]	Auckland, NZ	1989–2004
Reduced harvest value	US$4.2	*Lymantria dispar*[3]	USA	1933–1952
	US$219.6	*Lymantria dispar*[4]	Pennsylvania	1969–1987
	NZ$97.9	*Orgyia thyellina*[1]	New Zealand	1997
	US$35–US$5841	Defoliator insects[5]	Western USA	1990
	US$33.35–US$1670	*Bursaphelenchus* spp.[5]	Western USA	1990
	US$24.9–US$240.6	*Lachnellula willkommii*[5]	Western US	1990
	US$201–US$1500	*Ips typographus*[5]	Western USA	1990
	US$81.1–US$331.4	Annosus root disease[5]	Western USA	1989
	US$4.34	*Orgyia pseudotsugata*[7]	Pacific Northwest	1983
	US$2100	Plant pathogens[8]	USA	2000
	US$2100	Insect pests[8]	USA	2000
	NZ$6.1	*Dothistroma pini*[10]	New Zealand	1989
	NZ$22.5	*Dothistroma pini*[12]	New Zealand	2004
	NZ$5.4	*Diplodia pinea*[10]	Tarawera, NZ	1961–1989
	NZ$13.8	*Cyclaneusma minus*[9]	New Zealand	1989
	NZ$50.9	*Cyclaneusma minus*[11]	New Zealand	2001
	NZ$60.8	*Cyclaneusma minus*[12]	New Zealand	2004
	NZ$3.6	*Armillaria* spp.[9]	New Zealand	1989
	NZ$37	*Armillaria* spp.[12]	New Zealand	2004
	US$108–US$999	*Cronartium fusiforme*[14]	Southern USA	1992
Control	NZ$1.2/year	*Dothistroma pini*[9]	New Zealand	1989
	NZ$1.6/year	*Dothistroma pini*[12]	New Zealand	2004
	US$0.66	*Orgyia pseudotsugata*[7]	Pacific Northwest	1983
	US$49	*Cronartium fusiforme*[14]	Southern USA	1992
	NZ$34.7	*Orgyia thyellina*[1]	New Zealand	1997
Urban forest loss	NZ$1.5	*Ophiostoma novo-ulmi*[2]	New Zealand	1993
	NZ$10 100	*Ophiostoma novo-ulmi*[2]	New Zealand	1999
	NZ$116.7	Forest pathogens[13]	New Zealand	2003
	NZ$290.5	*Lymantria dispar*[6]	New Zealand	Undated
	NZ$1.5	*Orgyia thyellina*[1]	Auckland, NZ	1997

* Estimates are not directly comparable due to differences in methodology, year of valuation, area of pest impact, etc.

† Cost estimates are nominal, varying in their base year, and are in different currencies.

Sources:

[1] G.Horgan (unpubl. data)
[2] Ministry of Agriculture and Forestry (pers comm.)
[3] Perry (1955)
[4] Pennsylvania Bureau of Forestry (in Gottschalk 1990)
[5] USDA Forest Service (1991)
[6] Forest Health Advisory Committee (1997)
[7] Rose (1983)
[8] Pimentel *et al.* (2000)
[9] Sweet (1989)
[10] New (1989)
[11] Bulman (2001a)
[12] Bulman (unpubl. data)
[13] Auckland Uniservices (2003)
[14] Cubbage *et al.* (2000)

reduction costs due to Cyclaneusma needle-cast and Armillaria root disease. New (1989) estimated that losses due to Dothistroma needle-blight exceeded $7.00/ha annually in the North Island, and Diplodia dieback cost more than $1.30/ha annually in affected areas.

Bulman (unpubl. data), following the methodology of Sweet (1989) and making use of more up-to-date information on pest impacts, estimated the economic losses due to Cyclaneusma needle-cast, Dothistroma needle-blight, Armillaria root disease, and other exotic diseases of minor significance, to be $146 million/year. This is four times the cost estimated by Sweet (1989) due, in part, to Bulman (unpubl. data) including volume losses caused by Dothistroma needle-blight (Sweet (1989) considered only spray costs), and higher volume losses associated with Armillaria root disease.

Economic Costs of Exotic Forest Pests

Cost-benefit analysis places an economic value on the costs and benefits associated with exotic forest pests. This section describes these costs and benefits, and how they can be estimated. Economic costs associated with the arrival and establishment of an exotic pest include the cost of eradication, lost forest sector revenue due to reduced harvests and increased pest control costs, lost export markets due to trade bans and phytosanitary regulations, and the cost of urban forest protection (Table 1).

An eradication programme to prevent spread and establishment often follows detection of a significant pest. The costs associated with eradication include spraying, trap setting and monitoring, public education, possible health costs, and research (USDA Forest Service 1991). Costs associated with eradication programmes carried out by the New Zealand Ministry of Agriculture and Forestry have ranged from $4 million to $100 million (Table 1).

The most direct cause of loss of commercial forestry revenue is the reduction in harvest volumes and log quality (Table 1) due to increased tree mortality and defects, and decreased growth rates (Gottschalk 1990; Holmes 1991; USDA Forest Service 1991; van der Pas, Bulman & Horgan 1984; van der Pas, Slater-Hayes, Gadgil & Bulman 1984; Bulman & van der Pas 2001). Estimates of harvest reductions can be calculated from the rate of spread of a pest, the proportion of trees that will die (USDA Forest Service 1991), and growth reduction estimates from growth models (Perry 1955; Cubbage *et al.* 2000). The use of these estimates is complicated by potential changes in the mix of log grades. Van der Pas, Slater-Hayes, Gadgil & Bulman (1984) predicted that Cyclaneusma needle-cast would result in 25% fewer logs with a small-end diameter greater than 400 mm. Estimating revenue losses associated with harvest reductions is further complicated by changes in management, such as thinning of dying or malformed trees, to mitigate losses. Harvest reductions are often valued at current log prices, though some studies (e.g., Holmes 1991; USDA Forest Service 1991) have employed market models to endogenously calculate price changes associated with pest establishment.

The cost of programmes to control the effect of exotic pests on forest growth is another source of revenue loss in commercial forestry (Table 1). While control programmes commonly use pesticides, they may involve changes in silvicultural practices (van der Pas, Slater-Hayes, Gadgil & Bulman 1984; Bulman 2001b) or breeding for disease resistance (Carson 1989; Cubbage *et al.* 2000). The annual spray programme for control of *Dothistroma pini* in the North Island of New Zealand covers 2000 to 180 000 ha (Bulman unpubl. data), at a cost of $1.0 million to $1.8 million (G.Horgan unpubl. data). This is approximately $15/ha of infected forest area (van der Pas, Bulman & Horgan 1984). The cost of spraying white-spotted tussock moth (*Orgyia thyellina* Butler) with a pesticide in New Zealand was

$360/ha (Ministry of Forestry 1997). Compounded research costs to breed for fusiform rust resistance in pines in the US South were US$49 million in 1992, at a 4% real discount rate (Cubbage *et al.* 2000).

A further cost to commercial forestry is the opportunity cost associated with restricted forest management options (Sweet 1989). For example, planting of alternative species may not be possible because they are susceptible to damage from pests. Another example is the reduced possibility of a low initial to final-crop stocking ratio in stands affected by Cyclaneusma needle-cast, where the best method of control is to carry out a late thinning (van der Pas, Slater-Hayes, Gadgil & Bulman 1984; Bulman 2001b).

A final source of revenue decline for commercial forestry arises from reduced exports of raw logs and green timber due to phytosanitary regulations and trade bans imposed in export markets (Christie 1993; Tkacz 2002; Self 2003). This cost is dependent on several factors — the size of markets imposing bans, price impacts associated with the ban, the potential for increased domestic processing, and the existence of alternative markets. Some of these factors will mitigate the economic effect of bans, making estimates based on the current value of a market too high.

The economic costs associated with the effect of exotic forest pests on urban forests (Table 1) include the value of lost enjoyment of backyard recreation and natural beauty (Marler & McCrea 1977), lost property value, and increased maintenance costs (Gottschalk 1990). Methods used to assess the size of these costs include valuation of the cost of tree removal and replacement (Horgan, unpubl. data), estimates of control programmes (Gottschalk 1990), and hedonic pricing* of the contribution of trees to property values (Anderson & Cordell 1985; Tyrväinen 1999). Gottschalk (1990) cited a figure of US$62 per household spent on control of the Asian gypsy moth (*Lymantria dispar* L.). United States hedonic pricing studies estimate the presence of trees contributes 3% to 10% to the value of the average property (Morales *et al.* 1976, 1983; Anderson & Cordell 1985). Assuming that New Zealanders have the same preference for trees on their property as homeowners in the United States, the loss of trees due to an exotic pest would result in a $5,250 to $17,500 decline in property value (median property value $175 000 — Grimes *et al.* 2003). Homeowners are therefore likely to invest the smaller sum required to control pest damage by spraying or replacing affected trees.

Additional costs associated with the establishment of exotic pests include:

(1) Lost tourism revenue due to loss of natural forest (Gottschalk 1990);

(2) Loss of wildlife and fish habitat (Gottschalk 1990);

(3) Changes in water yield and quality due to forest defoliation (Gottschalk 1990);

(4) Lost biodiversity due to forest loss (Simpson 2002).

These costs are particularly important in New Zealand's natural forests. The costs could be large, and potentially exceed the costs in plantation and urban forests. Estimation of their magnitude is, however, complicated by the difficulty of estimating their market value. For this reason these costs were not included in the study reported here.

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* Hedonic pricing provides a basis for the relationship between the price of a good and the attributes embodied in the good (Lucas 1975).

METHODS

With the exception of that by Carter (1989), previous New Zealand studies have been *ex post* cost-benefit analyses for specific pests and regions. This paper presents a general estimate of the potential costs of exotic forest pests in New Zealand. The more general approach means there is greater uncertainty surrounding economic costs and benefits, and levels of risk. To consider this uncertainty, sensitivity analyses were carried out providing a range of estimates.

The benefit of forest health and biosecurity research was calculated as the difference between economic losses due to exotic forest pests **with** such research ("increased biosecurity research" scenario) and **without** ("status quo" scenario).

Status Quo

This study estimated the economic effect of significant exotic forest pests on the New Zealand forest-growing industry and urban forest estate. For the purposes of the study, a "significant" pest is defined as one for which the economic losses associated with the pest establishing itself in New Zealand would exceed the cost of control and eradication. Based on historical forest pest arrivals (Forest Research, unpubl. data) it was assumed that each year, on average, 0.60 significant pests of *P. radiata* and 6.00 pests of other species would arrive requiring eradication or control. The number of pests was further categorised by their potential impact: high, medium, or low (Tables 2 and 3), based on Carter's categorisation (1989, Tables 3 and 4), and an inventory of potential forest pest introductions (Flux *et al.* 1993, Appendix 5).

The economic cost of the arrival of a significant exotic forest pest was calculated as the sum of costs associated with:

(1) An eradication programme

(2) A control programme to reduce forest yield losses to zero

(3) Reduced value of harvests due to yield declines

(4) Household expenditures to control the exotic pest

(5) Replacement of affected trees in the urban forest.

The expected economic cost associated with each of the above is dependent on the probabilities of pest arrival, detection, eradication, and successful control (Fig. 1). For example, if a single high-impact pest affecting *P. radiata* is detected and is eradicable, the economic cost associated with the pest is the cost of eradication, $55 million in the example given in Fig. 1. Given the assumed likelihoods that the pest is detected and eradicable (Fig. 1), there is a 32%/year probability of needing to eradicate an exotic pest (60%/year × 53%/year = 32%/year). This implies an expected eradication cost of 32%/year × $55 million/pest = $18 million/year per pest. If a pest is not detected early and a control is not available, the economic cost associated with the pest is the cost associated with yield reduction, $31 million in the example. Given the likelihoods that the pest is not detected early and a control is not available (Fig. 1), there is a 6%/year probability of yield reduction (40%/year × 15%/year = 6%/year). This implies an expected cost due to yield reduction of 6%/year × $31 million/pest = $1.9 million/year per pest.

TABLE 2–Number of pest introductions per year potentially affecting *Pinus radiata*, plantation forest yield reduction, and proportion of plantation forest estate affected.

Impact class	Number of introductions	Status quo		Research	
		Yield reduction (%/year)	Proportion of estate (%)	Yield reduction (%/year)	Proportion of estate (%)
High	0.13	8.0	10.0	8.0, 6.0, 4.0‡	10.0, 7.5, 5.0
Medium	0.00	5.0	9.0	5.0, 3.0, 1.0	9.0, 6.8, 4.5
Low	0.47	1.0	6.0	1.0	5.0
	0.60*	2.5†	6.9†	2.5, 2.1, 1.7	6.1, 5.5, 5.0

* Total number of introductions.
† Weighted average yield reduction and proportion of estate.
‡ Low, average, and high research impact, respectively.

TABLE 3–Number of pest introductions per year potentially affecting species other than *Pinus radiata*, proportion of urban forest estate affected, and proportion of households carrying out pest control.

Impact class	Number of introductions	Status quo		Research	
		Proportion of estate (%)	Proportion of households (%)	Proportion of estate (%)	Proportion of households (%)
High	0.93	20.0	20.0	15.0, 10.0, 5.0‡	15.0, 10, 5.0
Medium	0.67	10.0	10.0	10.0, 5.0, 0.0	10.0, 5.0, 0.0
Low	4.40	5.0	5.0	5.0, 2.5, 0.0	5.0, 2.5, 0.0
	6.00*	7.9†	7.9†	7.1, 3.9, 0.8	7.1, 3.9, 0.8

* Total number of introductions.
† Weighted average proportion of estate and proportion of households.
‡ Low, average, and high research impact, respectively.

The likelihood a pest is detected early is 60%, based on Bulman *et al.* (1999). The 53% likelihood a pest is eradicable is from Carter (1989) and Flux *et al.* (1993, Appendix 5). Given the uncertainty around this figure (Carter 1989), the cost-benefit analysis was repeated for the values 50% and 70% in a sensitivity analysis. The assumed cost of eradication, $55 million/pest (Table 4), is the average cost of the eradication programmes for white spotted tussock (*O. thyellina*) and painted apple moths (*Teia anatoides* Walker) (Table 1).

The cost of control was calculated as the net present value (NPV, calculated using a 10% discount rate) of the annual costs from the time of the pest's arrival to 2070. These annual control costs were a function of the per-hectare cost of control (Table 4), the area of plantation forests (Ministry of Agriculture and Forestry 2000), and the proportion of forest estate requiring control (Table 2). The last increased linearly from 0% at 8 years after pest establishment to its maximum (depending on the pest impact class, *see* Table 2) 25 years after pest establishment. New Zealand's plantation forest area was assumed to increase, from 1.80 million ha in 2003, by 40 000 ha/year until 2040 (Ministry of Agriculture and Forestry 2000). After 2040 the forest area was assumed constant. Control costs were $130/ha, based on the average of $15/ha for Dothistroma needle-blight (van der Pas, Bulman & Horgan 1984) and $250/ha for Cyclaneusma needle-cast (Hood & Bulman 2001). Given the uncertainty around this figure, the cost-benefit analysis was repeated for

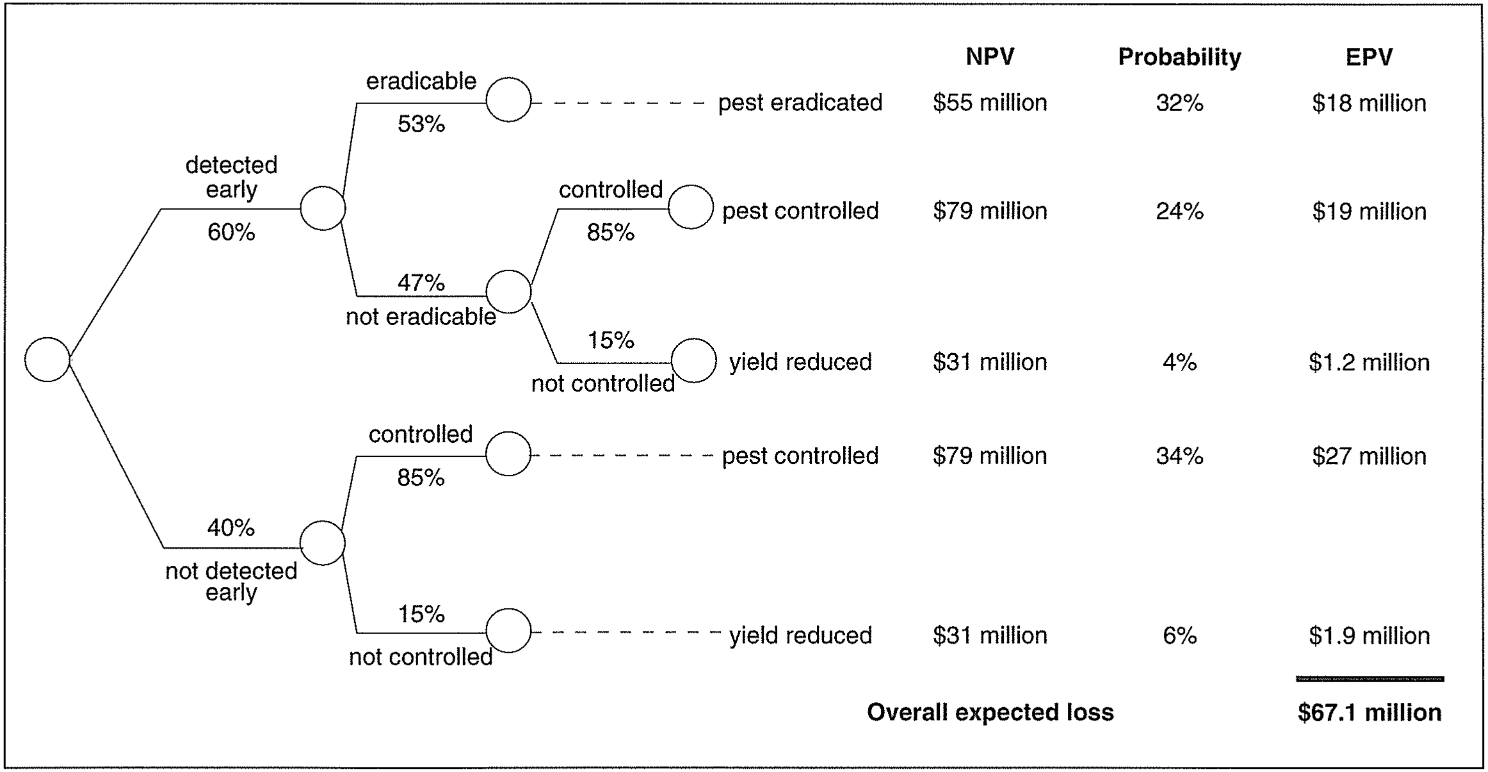

FIG. 1–Net present value (NPV) and expected present value (EPV) for different outcomes associated with the arrival of a single high-impact pest affecting New Zealand *Pinus radiata* plantation forests.

TABLE 4–Cost-benefit analysis assumptions

Variable	Units	Value		Source
		Status quo	Research	
Cost of research programme	$\$10^6$ /year	0.0	3.5	
Discount rate	%/year	10.0	10.0	
Log price	$\$/m^3$	50.00	50.00	Bulman (unpubl. data)
Cost of pest eradication programme	$\$10^6$/pest	55.0	55.0, 47.5, 40.0	
NPV of cost of pest control over stand rotation	$/ha	100.0, 130.0, 160.0	100.0, 75.0, 50.0	
Annual new land planting rate	10^3 ha/year	40.0	40.0	
NPV of cost of pest control by households affected	$/household	50.00	50.00	Horgan (unpubl. data)
Cost of urban tree replacement	$/tree	2600	2600	Treeby (1998)
Annual increase in housing stock	%/year	1.0	1.0	
Probability pest is eradicable	%	40.0, 53.0, 60.0	40.0, 53.0, 60.0	Carter (1989)
Probability of early detection	%	50.0, 60.0, 70.0	70.0, 80.0. 90.0	Bulman *et al.* (1999)
Probability pest can be controlled	%	75.0, 85.0, 95.0	95.0, 97.5, 100.0	

the values $100/ha and $160/ha in a sensitivity analysis. The proportion of forest estate requiring control (Table 2) was estimated based on the extent of spread of the two diseases (Forest Research, unpubl. data).

The value of reduced harvests due to an exotic pest was calculated as the NPV of annual reduced harvests from the time of the pest's arrival until 2070. The reduction in harvest value in each year was a function of the potential harvest (Ministry of Agriculture and Forestry 2000, base scenario) from 2000 to 2070, the percentage reduction in annual harvest due to the pest (Table 2), and the proportion of the annual harvest affected. The last was the same as the proportion of the forest estate requiring control (Table 2). The yield reduction (Table 2) was estimated based on historical information on the impact of Cyclaneusma needle-cast and Dothistroma needle-blight (Forest Research, unpubl. data). The value of the lost harvest was calculated for an average stumpage price of $50/m^3 (Bulman unpubl. data). It was assumed that, of the 40% of pests that evade early detection and become established in the plantation estate, 75% to 95% could be controlled to an extent that harvest reductions due to the pest were negligible (Table 4). This implies that 5% to 25% of pests evading early detection would result in significant yield reductions. The significant forest pests present in New Zealand (*Ophiostoma novo-ulmi* Brasier (causing Dutch elm disease), *Dothistroma pini*, *Cyclaneusma minus* (Butin) DiCosmo *et al.*, *Nectria fuckeliana* Booth, *Armillaria* spp., painted apple moth *Teia anatoides*, *Uraba lugens* Walker, *Paropsis charybdis* Stål) can all theoretically be controlled; hence the assumption of 95% control is not unrealistic. However, recognising that there is uncertainty around this estimate (Bain, pers. comm.), a 75% level of control was considered in a sensitivity analysis.

The cost of household forest pest control was calculated as the NPV of the annual costs from the time of the pest's arrival to 2070. These annual control costs were a function of per-household cost of control (Table 4), the number of households (Statistics New Zealand 2004b), and the proportion of households carrying out control (Table 4). The latter increased linearly from 0% at 8 years after pest establishment to its maximum (depending on the impact class, *see* Table 3) 25 years after pest establishment. The number of households in New Zealand was assumed to increase from 1.44 million households in 2001 by 1% annually until 2040, after which the number of households was constant.

For a proportion of the urban forest estate in New Zealand (Table 3) it was assumed that the only method of control would be to fell, remove, and replace infected trees, the method of control used for Dutch elm disease. The cost of such action was a function of the per-tree cost of replacement (Table 4), the number of trees in New Zealand's urban forest estate, and the proportion of trees that would require replacement each year (Table 3). The last was increased linearly from zero, 8 years after pest establishment, to the maximum proportion of trees replaced, depending on the impact class (Table 3), 25 years after pest establishment. The cost of replacement was calculated assuming that affected trees were replaced with a species that would not be affected. The number of trees in New Zealand's urban forest estate was assumed to be 20 million in 2001. The actual number is unknown; therefore, a sensitivity analysis was performed adjusting the number of trees by ±10%.

Increased Biosecurity Research

The assumptions described above represent the status quo. Increased biosecurity and forest health research was assumed to influence the following (Tables 2, 3, and 4):

(1) Probability of early detection;
(2) Cost of pest eradication;
(3) Cost of pest control in plantation forests;
(4) Percentage yield reduction in plantation forests;
(5) Proportion of forest estate requiring pest control;
(6) Probability of successful control;
(7) Proportion of households which need to control the pest;
(8) Proportion of urban forest estate that will require replacement.

Forest health research could increase the probability of early detection of a pest, through improved pest survey methods. Estimates of the impact of research on improved rates of early pest detection for random and drive-through plots are based on the work of Bulman *et al.* (1999), and surveys of high-risk sites (Forest Research, unpubl. data). Estimates of improvements in pest detection surveys (Table 5) — for example, using small plots rather than inspection by foot in parks and reserves — suggest a 4% to 54% increase in the probability of early detection. Based on the work of Bulman *et al.* (1999) the probability of early detection was assumed to improve from 50–70% under the "status quo", to 70–90% under "increased research" (Table 4).

TABLE 5–Improvements in probability of detection for different methods of pest detection survey (source: Bulman *et al.* 1999).

Survey	Status quo	Improved	Increase (%)
Drive through	63.8	86.0	34.8
Random forest plots	69.1	71.7	3.8
High-risk-site surveys	50.0	77.0	54.0

The cost of pest eradication was assumed to decrease to between $55 million and $40 million per pest. This reflects both improved methods of detection increasing the likelihood of early detection, which reduces the eradication area, and improved methods of eradication. Because few eradication programmes have been carried out, the magnitude of the impact of research is uncertain; hence, a range was used.

The cost of pest control was assumed to decrease to between $100 and $50/ha. The proportion of forest estate requiring pest control, and the reduction in harvests 25 years after the arrival of a pest, would also decrease (Table 2). These impacts of research reflect the potential development of pest-resistant breeds and/or the use of biocontrols to manage pests. The assumed magnitude of impacts of research on these are based on evidence of the contribution of research to reducing the impact of Cyclaneusma needle-cast and Dothistroma needle-blight. For *Cyclaneusma minus*, no economic chemical controls have been found, but silvicultural control measures were effective (Bulman 2001b). The cost of controlling *Dothistroma pini* has been reduced due to improved aerial spraying methods (Forest Research Institute 1988) and breeding for disease resistance (Carson 1989). Comparison of spraying efficiency of three different systems used to spray 600 ha of forest infected with *D. pini* (Forest Research Institute 1988) suggests that improved spraying efficiency reduced costs by 50% to 60%, depending on flying, labour, and chemical costs. Because potential improvements in the probability of successful control are uncertain, a range of improvements from 95% to 100% likelihood of successful control was used.

The impact of exotic forest pests on yield reductions and proportion of *P. radiata* estate may be inferred from the impact of Dothistroma needle-blight and Cyclaneusma needle-cast on New Zealand's plantation forests. However, it is difficult to determine the impact of exotic pests before the effects of research. To reflect this uncertainty a range of improvements in yield reduction and proportion of estate affected under the research scenario was used (Table 2). Some evidence is available from the proportion of estate affected by Dothistroma needle-blight in a season when control spraying was not carried out to specification (Forest Research, unpubl. data). From 1998–99 to 2003–04, on average 85 000 ha (5% of the plantation estate) were sprayed. In 2001–02, due to management decisions and difficult conditions, many stands were either not sprayed or sprayed at the wrong time. In the following season, 180 000 ha (10% of the plantation estate) were affected by Dothistroma needle-blight. Climatic conditions were favourable for disease in 2002–03, but the less-than-optimum spraying in the previous year contributed to the need for an expanded spray programme.

The proportion of households requiring pest control, and urban forest estate requiring replacement, would decrease as shown in Table 3, though the cost of household control was assumed unchanged. Because the only example of control of an exotic pest in the urban forest estate is Dutch elm disease, the magnitude of the impact of research is uncertain; hence, a range was used (Table 3).

The difference between the costs associated with exotic pests under the "status quo" and under "increased biosecurity research" is a measure of the potential benefit of the research. Because the impact of forest health research is uncertain, benefit-cost ratios were calculated for a range of values of each variable influenced, keeping all other variables at their average value. Benefit-cost ratios were also calculated for the most conservative and most optimistic values to provide bounds on the potential economic benefits of forest health research. The estimates of the annual expected costs associated with exotic forest pests from 2000 to 2040 were discounted to 2000 using a 10% real discount rate.

To test the sensitivity of the estimates to assumptions, the cost-benefit analysis was performed for different values of (1) discount rate, (2) proportion of pests that are eradicable, (3) probability that the pest can be controlled, (4) plantation forest planting rates, (5) cost of pest control on plantation forests, (6) yield reduction, (7) proportion of plantation forest affected by pests, (8) number of trees in the urban forest estate, and (9) cost of urban tree replacement. Each of these variables was adjusted while other variables were kept at their average values.

RESULTS AND DISCUSSION

Under the status quo scenario, the net present economic losses associated with new exotic forest pests range from $3,750 million to $20,273 million depending on the discount rate (Table 6). For a 10% discount rate, losses are $6,228 million under the status quo, compared with $1,172 million under the biosecurity research scenario (Table 6). This implies a net present benefit of $5,056 million and a benefit-cost (B:C) ratio of 147:1 for the $3.5 million annual cost of the research programme. For the most optimistic and

TABLE 6–Net present value (NPV), benefit, and benefit-cost (B:C) ratio from sensitivity analyses.

Variable	Unit	Range (%)	Value		NPV ($\$10^6$)		Benefit	B:C Ratio
			Status quo	Research	Status quo	Research		
Discount rate	%/year		6.0	6.0	20,273	3,989	16,284	307:1
			8.0	8.0	10,894	2,065	8,829	211:1
			10.0	10.0	6,228	1,172	5,056	147:1
			12.0	12.0	3,750	721	3,029	105:1
Probability pest is eradicable	%		40.0	40.0	6,393	1,166	5,227	152:1
			53.0	53.0	6,228	1,172	5,056	147:1
			60.0	60.0	6,138	1,175	4,963	145:1
Probability of early detection	%		50.0	80.0	6,340	1,172	5,168	151:1
			60.0	80.0	6,228	1,172	5,056	147:1
			70.0	80.0	6,138	1,172	4,997	145:1
Probability pest can be controlled	%		75.0	97.5	9,436	1,172	8,264	241:1
			85.0	97.5	6,228	1,172	5,056	147:1
			95.0	97.5	3,020	1,172	1,848	54:1
Planting rate	10^3 ha		10.0	10.0	6,154	1,133	5,020	146:1
			20.0	20.0	6,178	1,146	5,032	147:1
			40.0	40.0	6,228	1,172	5,056	147:1
			60.0	60.0	6,277	1,197	5,079	148:1
Cost of pest control	$/ha		100.0	75.0	6,167	1,172	4,995	146:1
			130.0	75.0	6,228	1,172	5,056	147:1
			160.0	75.0	6,288	1,172	5,116	149:1
Yield reduction	%/year	−10	2.3	2.1	6,227	1,172	5,055	147:1
		0	2.5	2.1	6,228	1,172	5,056	147:1
		10	2.8	2.1	6,228	1,172	5,056	147:1
Proportion of plantation estate affected	%	−10	6.2	5.5	6,201	1,172	5,029	147:1
		0	6.9	5.5	6,228	1,172	5,056	147:1
		10	7.6	5.5	6,255	1,172	5,083	148:1
Number of trees in urban forest estate	10^6 trees	−10	18	18	5,728	1,132	4,596	134:1
		0	20	20	6,228	1,172	5,056	147:1
		10	22	22	6,727	1,211	5,515	161:1
Cost of urban tree replacement	$/tree	−10	2340	2340	5,728	1,132	4,596	134:1
		0	2600	2600	6,228	1,172	5,056	147:1
		10	2860	2860	6,727	1,211	5,515	161:1

conservative estimates of the impact of research, losses due to pests range from $2,708 million to $339 million, with a net present benefit of $3,519 million to $5,888 million (B:C ratio 103:1 to 172:1). These results indicate that there is considerable benefit to investing in biosecurity research to reduce economic losses in the New Zealand forest-growing industry and urban forest estate.

Though direct comparison is not possible, because of differences in methodology and assumptions, this study's estimate of the economic loss due to pests is larger than a previous estimate by Carter (1989). This reflects the inclusion of the costs of pests in both urban and commercial forests, and the impact of successive pest arrivals until 2040.

Estimates of the benefit of biosecurity research in Table 7 reflect the uncertainty regarding the potential impacts of research on variables influenced. For most variables influenced by research, the range of possible impact has a minor effect on the benefit of

TABLE 7–Cost-benefit analysis results.

Variable	Unit	Range	NPV ($\$10^6$)		B:C Ratio*
			Research	Benefit	
Probability of early detection[1]	%/year	70.0	1,169	5,059	148:1
		80.0	1,172	5,056	147:1
		90.0	1,175	5,053	147:1
Cost of pest eradication programme[2]	$\$10^6$	55.0	1,205	5,023	146:1
		47.5	1,172	5,056	147:1
		40.0	1,139	5,089	148:1
Probability pest can be controlled[3]	%	95.0	1,554	4,674	136:1
		97.5	1,172	5,056	147:1
		100.0	790	5,438	159:1
Cost of pest control over stand rotation[4]	$/ha	100	1,218	5,010	146:1
		75	1,172	5,056	147:1
		50	1,126	5,102	149:1
Yield reduction[5]	%/year	Low	1,172	5,056	147:1
		Average	1,172	5,056	147:1
		High	1,172	5,056	147:1
Proportion of plantation estate affected[6]	%	Low	1,181	5,047	147:1
		Average	1,172	5,056	147:1
		High	1,163	5,065	148:1
Proportion of urban forest estate affected[7]	%	Low	1,514	4,714	137:1
		Average	1,172	5,056	147:1
		High	830	5,398	157:1
Proportion of households affected[8]	$/tree	Low	1,524	4,704	137:1
		Average	1,172	5,056	147:1
		High	802	5,426	158:1

* Benefit-cost ratio.

[1] Keeping status quo probability of early detection as 60%.

[2] Keeping status quo cost of eradication as $55 million.

[3] Keeping status quo probability of control as 85%.

[4] Keeping status quo cost of pest control as $130/ha.

[5] Keeping status quo average yield reduction as 2.5%/year.

[6] Keeping status quo average proportion of plantation estate affected as 6.9%.

[7] Keeping status quo average proportion of urban forest estate affected as 7.9%.

[8] Keeping status quo average proportion of households affected as 7.9%.

research (Table 7). Only differences in the improvement in the probability of controlling pests leads to a difference in the benefit of research, from $4,674 million for 95% to $5,438 million for 100%. Though these differences were comparatively small, this suggests this probability is an important influence on the economic impact of exotic forest pests. The extent to which research effort should focus on pest control is dependent on the cost of additional effort and improvements achieved — something that could be considered in a future cost-benefit analysis.

The benefit of research is also influenced by the impact of research on the proportion of urban forest estate and households affected. If research is very successful, and keeps the effect of pests low, the benefit is $5,398 million (Table 7). This reflects the significant economic impact of exotic pests on the urban forest estate, with this cost representing 93% of the total net present cost of pests under the status quo.

Results of the sensitivity analysis are given in Table 6. The net present benefit of biosecurity research is $3,029 million to $16,284 million, depending on the discount rate (Table 6). Given the long-term nature of forestry, the benefits of biosecurity research are greater at lower discount rates.

An increase from 40% to 60% in the probability a pest is eradicable reduces the net present benefit of research from $5,227 million to $4,963 million (Table 6). This is due to the increase in pests being eradicated and hence reduced impacts on plantation and urban forests where benefits from improvements in control costs and yield losses from research would be realised.

Uncertainty around the probability of early detection under the status quo influences the estimated benefit of research, ranging from $5,168 million for a 50% probability to $4,997 million for 70%. This is due to the greater improvement, due to research, in the likelihood of detection and the associated increase in eradication success. Uncertainty around the probability of pest control under the status quo also influences the estimated benefit of research, ranging from $1,848 million for 95%, to $8,264 million for 75% probability. This is due to two factors: firstly, the larger increase, due to research, in the probability of successful control; secondly, improvement in the probability of control increases the cost of control as more exotic pests face a control programme. This increased cost is, however, offset by decreased costs associated with yield reduction in plantations and more significantly, cost of tree replacement in urban forests.

The greater the rate of expansion of plantation forests, the greater the benefit of biosecurity research. For a planting rate of 10 000 ha/year the net present benefit is $5,020 million compared with $5,079 million for 60 000 ha/year (Table 6). This is due to the greater cost of pest control in the larger forest estate.

A higher cost of controlling exotic pests in plantation forests (Table 6) increases the benefits of biosecurity research. For a control cost of $100/ha annually under the status quo the net present benefit is $4,995 million. This increases to $5,116 million for control costs of $160/ha annually reduced to $75/ha annually with research. The increased benefit is due to several factors. Firstly, there is a greater reduction in the cost of control due to research, for the higher control cost. Secondly, with biosecurity research there is a reduction in the forest area requiring control. Thirdly, the likelihood of needing to control pests is reduced due to increased eradication success.

A 10% increase or decrease in the average yield reduction due to exotic pests has very little effect on the net benefit of biosecurity research, ranging from $5,055 million to $5,056 million (Table 6). This is due to the already low yield reduction, and the high likelihood of being able to control pests to prevent yield reduction. For these reasons a 10% increase or decrease in the proportion of plantation forest affected also has a small effect on the net benefit of biosecurity research, ranging from $5,029 million to $5,083 million.

The estimated benefit of research is sensitive to the range of values used for the number of trees in the urban forest estate and the cost of urban tree removal (Table 6). For a 10% lower cost of urban tree replacement or number of trees in the urban forest the net benefit of biosecurity research is $4,596 million, compared with $5,515 million for 10% higher values. The estimate of the value of the urban forest estate, therefore, has an important impact on the predicted benefits of biosecurity research.

CONCLUSIONS

The net present benefit of research was estimated to range from $3,519 million to $5,888 million depending on assumptions about the impact of research. For the $3.5 million annual cost of research, the benefit-cost ratio was 103:1 to 172:1. These results indicate that there is considerable benefit to the New Zealand forest-growing industry and urban forest estate from forest health and biosecurity research, in terms of reducing economic losses associated with exotic forest pests.

The economic impact of exotic pests on the urban forest estate is significant. Combined with the sensitivity of the predicted impacts of biosecurity research to estimates of the value of the urban forest estate, this suggests that improving the data used to estimate urban forest impacts would improve the overall estimate from the cost-benefit analysis. The Ministry of Agriculture and Forestry has begun the process of estimating this cost (Treeby 1998; Auckland Uniservices 2003); however, further work is needed, particularly on creating an inventory of New Zealand's urban forest estate.

Not included in this study were costs associated with the impact of exotic pests on New Zealand's natural forests. These costs, which include lost tourism, loss of wildlife habitat, and lost biodiversity, could be large. Determining their magnitude is complicated by the difficulty of estimating their market value. It is recommended that, to provide a more complete analysis of the benefit of forest health research, future work should evaluate the potential cost of introduced pests in the indigenous forest estate.

This study estimated the economic benefit of biosecurity and forest health research. The cost-benefit analysis developed also provides a framework for analysing the implications of changes to forest health policy and biosecurity strategies. For example, the cost of increasing port surveys can be weighed against the benefit of increased pest detection. Or, the potential benefit of treating imported cars to destroy exotic pests that arrive with these cars, can be weighed against the cost of the treatment.

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