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Pest fencing or pest trapping: A bio-economic analysis of cost-effectiveness

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Abstract Scofield *et al.* discredited the utility of pest-exclusion fences for restoring biodiversity partly on the grounds of unquantified costs and benefits. We estimated the discounted costs of mammal exclusion fences, semi-permeable ('leaky') fences and trapping, over 50 years and adjusted costs by their observed effectiveness at reducing mammalian predator abundance. We modelled data from two large predator management programmes operated by the New Zealand Department of Conservation. Using typical baseline costs and predator control efficacies (scale 0 to 1), the model predicted that an exclusion fence (efficacy 1.0) is the cheapest and most cost-effective option for areas below about 1 ha, a leaky fence (efficacy 0.9) is most cost-effective for 1–219 ha, and trapping (efficacy 0.6, based on 0.2 traps per hectare and a 1500-m buffer to reduce predator reinvasion) for areas above 219 ha. This ranking was insensitive to adjustments in efficacy, but reducing efficacy of leaky fences to 0.8 or increasing trapping efficacy to 0.7 reduced the cost-effective range of leaky fences by about 90 ha. Reducing trap maintenance costs from $300 to $100 per trap per year (e.g. using long-life lures), or reducing trap buffer widths to 500 m, significantly elevated trapping as the most cost-effective method for areas greater than 11–15 ha. These results were largely consistent with an ecological measure of effectiveness based on observed rates of recovery of two indigenous skink species inside exclusion fences or with trapping. The results support criticisms that exclusion fences are generally not cost-effective, but highlight the value of considering cheaper leaky designs for small- to medium-sized areas. Because this study is based largely on reductions in predator abundance, it has general application to broader biodiversity protection interests, but not to indigenous species that are highly sensitive to predation and only ever adequately protected on the mainland by exclusion fences.

Key words: *Oligosoma grande*, *Oligosoma otagense*, pest management, predator fence, trapping.

INTRODUCTION

Pest control is often required to sustain or recover species and ecosystems. Typically, there are several control options to choose from, and these will often differ in cost and effectiveness. While a number of non-economic factors drive decisions about which method to use (Hayward & Kerley 2009; Innes *et al.* 2012), there has been little robust quantitative analysis of the relative cost-effectiveness of pest control methodologies (although see Baxter *et al.* 2007; Bode & Wintle 2010; Bode *et al.* 2012). The problem is wider than pest control. Pullin and Knight (2005), for example, found that conservation managers in the UK and Australia do not use scientific evidence systematically to formulate management plans, due partly to a lack of empirical evaluation of biodiversity protection investments (Ferraro & Pattanayak 2006). In many countries, community groups and government agencies are creating 'biodiversity sanctuaries' either by suppressing pest numbers with trapping or poisoning or by eradicating pests inside large exclusion fences (Hayward & Kerley 2009; Burns *et al.* 2012; Dickman 2012). Two broad types of exclusion fence are used: expensive fences that exclude all mammalian pests; and cheaper, semi-permeable or 'leaky' fences, sometimes supplemented with trapping, which knowingly leak some mammalian pests. Fences that exclude mammals as small as house mice (*Mus musculus*) (herein referred to as an 'exclusion fence') are used where small mammals are a threat to biodiversity, such as in New Zealand and the Pacific islands. In Australia, leaky fences generally suffice because large predator species, namely cats (*Felis catus*) and foxes (*Vuples vulpes*), are the key threats. Note, the term 'leaky' does not imply design failure but a cheap (about $100 m^{-1}), intentionally semi-permeable design sufficient for achieving the required ecological outcome. Given the high cost of an exclusion fence, leaky designs are now being considered more widely as a cheaper alternative.

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Regardless of the method, all pest control options applied on a landscape scale (1000s of hectares) are expensive and often funded with public money, so there is much at stake when deciding on the 'best' method.

Scofield *et al.* (2011) recently reviewed the utility of pest-exclusion fences for species conservation in New Zealand, and discredited them partly on the grounds that cost–benefit analyses generally fail to adequately quantify ongoing costs and benefits. They questioned whether an exclusion fence is necessarily the optimum solution. Calculating cost-effectiveness is not straightforward because it depends on the scale, set-up costs, maintenance costs and efficacy of the method. Trapping, for example, has the advantage of relatively low set-up costs compared with mammal-proof fencing, but the maintenance costs are high and the method requires extensive application beyond the intended management area in order to control for pest reinvasion. Eradicating pests inside an exclusion fence, on the other hand, has large set-up costs but relatively low maintenance costs, and it maintains pests at zero, or near zero, densities. A key strategic question is whether it is more cost-effective in the long term to invest more in infrastructure that requires less maintenance, or to spend less on infrastructure and more on maintenance. And does cost-effectiveness depend on scale? New trap and lure technologies that are currently being developed (Spurr 1999; Gillies *et al.* 2012) may have potential to increase the cost-effectiveness of trapping, but they are still in the development stage and as yet unproven. Here we undertake some preliminary analyses using various assumptions of efficacy and trap maintenance costs to examine their potential for improving the cost-effectiveness of trapping.

We address these issues by comparing the cost-effectiveness of three pest control methods (trapping, a leaky fence and an exclusion fence) across a range of spatial scales. We focus on the efficacy of each method at reducing pest abundance as a starting point for decision making. Ideally, efficacy should be based on ecological outcomes but these are often difficult to quantify and specific to the taxa or ecological system of interest (see Shwiff *et al.* 2013). Pest abundance has more universal utility as a measure of pest control effectiveness and allows end-users to interpret results according to their interests. Nevertheless, we also investigate the cost-effectiveness of trapping and an exclusion fence at recovering populations of two species of endangered lizard (grand skink, *Oligosoma grande*, and Otago skink, *O. otagense*; Scincidae) (Reardon *et al.* 2012). We use a simple spreadsheet model to explore potential crossover points where one method becomes more or less cost-effective than another for a given scale of management. A number of adjustable parameters are included in the model, such as linear fence costs, fence maintenance costs, trap costs, trap density, number of traps serviced over a given period, frequency of servicing, contractor costs and control efficacy. Because of constant pest immigration into trapped areas, the model includes a trap buffer width that can be adjusted according to the mobility of the pest species. We use a set of plausible parameter values to explore which methods are most cost-effective for a given scale of management. We use sensitivity analyses to account for uncertainty in parameter values and to identify parameters that have the greatest impact on cost-effectiveness.

Our study focuses on methods for protecting biodiversity from introduced mammalian predators on mainland systems over small- to medium-sized areas (a few hectares, to a few thousand hectares) using data collected from real management operations. It does not examine poisoning as a control method, nor does it examine cost-effectiveness of managing areas bounded by natural barriers such as peninsulas. Finally, our results do not apply to indigenous species that are extremely sensitive to predation (e.g. saddleback, *Philesturnus carunculatus*, and little spotted kiwi, *Apteryx owenii*, in New Zealand; and greater bilby, *Macrotis lagotis*, and rufous hare-wallaby, *Lagorchestes hirsutus*, in Australia) and only ever adequately protected on the mainland by exclusion fences where predators are eradicated or acutely suppressed. Rather, the study has general application to broader biodiversity protection aspirations.

METHODS

We estimated the set-up and maintenance costs (in NZ$) of each pest control method, and compared them with the extent to which each method reduced unwanted threats (i.e. abundance of introduced predators) or increased desirable resources (i.e. abundance of two endangered lizard species). The total and annualized costs of fencing and trapping were calculated over a 50-year period for areas up to 4000 ha using a simple spreadsheet accounting model in Microsoft Excel 2010.

Study sites

Cost and efficacy data were derived from two large predator control programmes in New Zealand operated by the Department of Conservation – at Macraes Flat, eastern Otago (trapping and exclusion fences), and Burwood Bush, Southland (leaky fences combined with trapping inside and immediately outside). Macraes Flat is the last stronghold for endangered grand and Otago skinks in eastern Otago (see Reardon *et al.* 2012). Their habitat consists of indigenous tussock (*Chionochloa* spp.) grassland and schist rock outcrops with indigenous shrubs (e.g. *Discaria toumatou* and

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Leptospermum scoparium). Skinks are protected from predators by either exclusion fences or an extensive grid of traps. Burwood Bush is the centre for captive rearing of the critically endangered bird, the takahē (*Porphyrio hotchstetteri*) (Miskelly *et al.* 2008). It is situated in central Southland in a mosaic habitat of remnant red tussock (*Chionochloa rubra*) grassland, remnant silver beech (*Nothofagus menziesii*) forest and developed pasture.

Trapping

The trapping programme at Macraes Flat was designed to provide a maximum plausible effort at a landscape scale to suppress predator species regarded as threats to lizards. The main predators were feral cats, weasels (*Mustela nivalis vulgaris*), stoats (*M. erminea*), ferrets (*M. furo*) and hedgehogs (*Erinaceus europaeus occidentalis*). Rats (both *Rattus rattus* and *R. norvegicus*) were occasionally caught but not sufficiently abundant in this system to be a major concern. The analysis used data gathered over 28 months from the start of December 2005 to the end of March 2008. This is the longest period for which the trap layout was sufficiently stable for linear regression analysis involving a total of 329 113 trap-nights (TN). The layout comprised just over 400 traps along 42 km of trap-lines covering about 2100 ha. The operational area at Macraes Flat has a substantial history of predator trapping before 2005, initially focused on feral cats then extending to mustelids (Tocher 2006). Twelve trap–bait combinations were used (six trap types and three bait types). Trap types used were the Conibear/Belisle SuperX #220 trap (Woodstream Corporation, St. Lititz, Pennsylvania/Minnesota Trapline Products, Pennock, Minnesota, USA) housed within an open-ended wooden box, Victor Soft Catch leg-hold trap (Woodstream Corporation, St. Lititz, Pennsylvania, USA) dug into the ground and hazed with natural cover, modified Timms possum trap with a widened keyhole entrance (KBL Rotational Moulders, NZ), DOC 250 'masher' trap (Curtis Metal Products, NZ) housed singly in wooden boxes with wire mesh ends, DOC 150 trap (Curtis Metal Products, NZ) housed in pairs in wooden boxes with wire mesh ends (with smaller entrance hole than DOC 250), and Mark VI Fenn trap (FHT Works, Worcester, UK) double-set under Philproof covers (Philproof Pest Control Products, Hamilton, NZ). All traps, apart from the leg-hold traps, were lethal. The three bait types used were chicken egg (*Gallus gallus*), unskinned gutted rabbit (*Oryctolagus cuniculus*) segments or occasionally hare (*Lepus europaeus*), and fish-based cat food (Whiskas Ocean Fish Platter) wrapped within loose weave cloth. The trap sets were deployed at 100-m spacing in a randomized block design (sets of 12 trap–bait combinations were repeated, with a random order of placement within each set of 12). The trap layout used approximately equal numbers of each trap–bait combination.

Baseline trap parameters used in the model comprised: trap density (0.2 ha^{-1}), trap costs ($60 per trap), set-up costs (based on 25 traps set per day at $350 per day for labour), annual servicing and maintenance costs ($300 per trap per year). A trap buffer width of 1500 m was used because the strongest recovery of skink populations was observed when protected by predator reinvasion over this distance (Reardon *et al.* 2012). Buffer widths were subtracted from the radius of the total area trapped (assumed circular) to derive the area 'protected'. The annual maintenance costs of traps were equivalent to $60 ha^{-1} $year^{-1}$ including labour for servicing leg-hold traps every day, and servicing lethal traps every week. It also included road maintenance, quad-bike maintenance and trap replacement every 7 years.

Exclusion fence

Two mammal-proof fences (about 9 and 18 ha, total length 2.9 km) were built by Xcluder Pest Proof Fencing (Cambridge, NZ) to protect skinks at two sites at Macraes Flat. These consisted of 6 × 24 mm stainless steel mesh built to a height of about 1.8 m with a subterranean skirt at the base and a metal rolled hood barrier at the top. Mammals within the fences were eradicated using the traps employed in the wider Macraes Flat operation, and toxins. Hand-laid carrot impregnated with sodium monofluoroacetate (1080), and magnesium phosphide fumigant (Magtoxin granules), were used to poison lagomorphs. Rodents were poisoned with brodifacoum-baited cereal pellets (Talon 20R) hand laid in bait stations. Most mammals were eliminated from inside the 18-ha fence within a month after it was closed in winter 2005, and from the 9-ha fenced area within a month after it was enclosed in 2007. Rabbits were more troublesome: although they were eliminated from the smaller fenced area in 2007, it took until August 2008 to eliminate them from the larger enclosure. Mice were a recurrent problem, and were detected and eradicated 3–4 times inside each fence. The fences have endured many extreme weather events, including heavy snowfalls and periods of high rainfall, causing erosion and damage to culverts and tracks but not necessarily the fence. The greatest threat to the fences has been from high winds, which have been the cause of most ongoing maintenance issues.

Baseline costs of an exclusion fence were modified where necessary to match the majority of fence projects across New Zealand outlined in Burns *et al.* (2012). Baseline parameters were: (i) cost per linear metre ($250, including materials, gates, culverts and installation); (ii) pest eradication costs (total costs fixed at $5000 for areas ≤ 10 ha and $500 ha^{-1} for areas > 10 ha, including traps, bait stations, toxins, ammunition and labour at $350 per day); (iii) annual maintenance costs (based on 4% of fence's capital value, including regular fence inspections and eradication costs following occasional pest incursions); and (iv) fence longevity (25 years, i.e. two replacements in 50 years). Fence length was calculated for any given area by fitting a power function to the data in table 5.1 (excluding peninsulas) of Burns *et al.* (2012).

$$\text{Fence length (m)} = 379.52 * \text{Area (ha)}^{0.5567} \quad (r^2 = 0.9836)$$

Leaky fence

Three leaky fences (4.4 km in total) at Burwood Bush were designed to be cat- and ferret-proof, and resistant to other predator species (weasels and stoats) deemed a predatory threat to takahē. Fence A was constructed in 1985 and

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covered an area of 85 ha. The fence was 1.2 m high, consisting of chicken wire mesh supported by tanalized fence posts spaced every 4 m. The bottom 20 cm was supplemented by a panel of square plastic welded mesh. Electric outriggers (7 kV) consisted of three parallel wires protruding horizontally out from the fence 20 cm above the ground, and another three wires protruding out from the top of the fence. The cost of this fence is unknown, but the similarly designed 2-ha fence B cost about $60 per linear metre in materials and labour. The 11-ha fence C was constructed in 2007/08 and was expanded in 2011. It was also 1.2 m high but the top outriggers consisted of five wires angled upwards at 45 degrees rather than horizontal. The 20-cm footing was solid flexible plastic rather than mesh. This fence cost $70 per linear metre. Predator trapping occurred inside and immediately outside the fences since their installation. Ninety-six unbaited run-through single-set DOC 200 traps in timber tunnels were spaced every 50 m along the external fence lines. The channelling effect of the fence on predators' trap interaction rates may have compensated for the fact that traps were not baited. Baited Warrior, Timms and Victor Soft Catch leg-hold trap were regularly moved to target cats close to the fences. Within the fences, DOC 150 and DOC 200 double- and single-trap sets were deployed in fixed locations. Within fence A, 124 traps were at 200-m spacing, and at 100-m spacing on the internal periphery. The other fences had traps ($n = 43$) only at the internal periphery at less than 100-m spacing due to their small size. Average trap density was 1.7 traps per hectare. While this density of lethal traps was quite high by conventional standards, traps were checked only every 90 days on average. Traps were baited with rabbit, hare or deer meat. We used the predator trap-catch data from 2009–2012 because currently available trap types were used in a consistent manner during this period. There were 382 139 TN in total (139 488 outside the fences and 242 651 inside). We included cats, ferrets, stoats, weasels, rats (both *R. rattus* and *R. norvegicus*) and hedgehogs in the analysis. No cats, ferrets or hedgehogs were trapped inside the fences, but some rats, weasels and stoats entered. Trap-catch rates for rats, weasels and stoats inside the fences, expressed as a percentage of those outside, were 15%, 12% and 2% respectively. We omitted the nights for traps inside fence A because their high density artificially deflated the trap rate considerably because there were so few captures. Results were insensitive to their exclusion.

Baseline costs of a leaky fence included: cost per linear metre ($120, including materials, gates, culverts and installation), pest eradication, fence maintenance costs and fence longevity (using same costs as an exclusion fence). This is a more expensive design than the Burwood Bush fences to reflect the fact that with current prices fence contractors cannot build a robust leaky fence for less than $120 per metre (John McLennan, pers. comm.). We included trapping inside leaky fences using the same baseline trapping parameters as above, but modified them for small fences, viz. 10 traps for areas up to 1 ha, 15 traps for areas up to 10 ha, 20 traps for areas up to 100 ha, then 0.2 ha^{-1} above 100 ha. All leaky fences included traps at 100-m intervals on the inside periphery. A trap buffer was not included as a baseline parameter, apart from a single line of traps on the external periphery at 100-m intervals.

Cost metrics

We used two cost metrics in the model: aggregated unadjusted total costs over 50 years, and aggregated discounted costs. Because more weight is typically placed on costs that accrue closer to the present day than those that occur later, discounting renders costs occurring in different time periods to present-day terms, or net present value (NPV), according to the formula:

$$\mathrm{NPV} = \sum_{t=1}^{\mathrm{T}} \frac{C}{(1+r)^t}$$

where C is the cost at each year t, for 50 years (T), and r is the discount rate.

We used an 8% discount rate because this is the default used by New Zealand Treasury for public sector cost-benefit analyses. We did not adjust for inflation. Net present values were annualized (often referred to as 'equal annual equivalents') to derive average costs, according to the formula in USEPA (2010):

$$\text{Annualized NPV} = \mathrm{NPV} * \left[\frac{r*(1+r)^{\mathrm{T}}}{(1+r)^{\mathrm{T}}-1}\right]$$

The equivalent annual cost is a constant per year cost of owning, operating and maintaining an asset or project over its lifetime (50 years in this case). It is estimated by multiplying the total NPV of costs by an annuity factor. Although volunteer input reduces costs, we fully costed all labour hours in order to make valid cost comparisons between methods. This also recognizes opportunity costs when people volunteer their time.

Efficacy calculations

The only efficacy measure that was common to all three pest control methods in this study was predator trap rate. This was set to zero inside an exclusion fence because enclosures were generally free of pests, apart from occasional ingressions of mice, which were generally dealt with quickly. For a leaky fence and trapping, we estimated the decline in probability of trapping a predator using the trap-catch data from Burwood Bush and Macraes Flat. These data were analysed with generalized linear models using logistic regression and a binomial distribution (capture or no capture). Models examined how various factors and their interactions affected catch, but the interaction terms were excluded in order to simplify interpretation of the buffer effect. The models produced maximum likelihood estimates of the $\log_e$ odds by which each factor affected the TN outcome. Analysis was carried out using the statistics package R. In order to model binary outcomes, the number of nights a trap was available was divided into the number of nights a predator was caught and the number of nights it was not caught. This binary division does not adjust for trap availability (e.g. catch of a non-target species or trap occupancy by a target animal between checks). Such an adjustment would not have had much impact on the results as trap availability at both sites was typically above 99%.

All candidate models were generated and ranked by AIC (Akaike's information criteria) – the model with the lowest AIC explains the variation in the data without excessive

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complexity. We used the model weights derived from the difference from the best-ranked-model's AIC to ensure that all terms in the selected model were necessary and that no other terms of importance had been omitted. This process derived the best-fit model with maximum predictive power (i.e. low residual deviance without over-fitting data). Because the models estimate effects as changes to the log odds, the buffer effect for the trapping data is a per-metre log odds ratio. By calculating the log odds change at particular distances from this gradient, and raising the base 'e' to the power of that value, odds ratios between the edge of trapping and various buffer distances into the trapped area were calculated. These odds ratios are relative probabilities from 0 (no predators) to 1 (unmanaged predators), showing either the proportional catch of predators at the buffer distance compared with the catch at the outside edge of the trapped area, or the proportional catch inside and outside a leaky fence.

For cost-effective comparisons between trapping and an exclusion fence, we used an additional measure of efficacy based on observed rates of population increase for grand and Otago skinks under these two management regimes, measured by Department of Conservation staff between 2006 and 2012. Monitoring methods are outlined in Reardon *et al.* (2012). Additional measures have been taken since the Reardon *et al.* (2012) study, and all data are used here. The mean exponential rate of increase of skink populations over this period was estimated by log-transforming the time series data and calculating the slope of the fitted linear regression. We recognize that rates of increase over 6 years are an over-simplification of trends over the 50-year time frame for which the management costs are modelled. Population models over this extended period require knowledge of density-dependence and carrying capacities, which are not available for grand and Otago skinks. Therefore, efficacy values derived from the observed rates of increase relate to short-term population recovery, not to longer-term population size or population viability. No skink data were available from a leaky fence.

We used cost-effective analysis to rank the three pest control options. Cost-effectiveness was calculated by dividing the annualized NPVs by the efficacy of each option. This can be loosely interpreted as the cost of the 'effective area' that is fully protected by a given pest control option. For example, if a 100-ha area costs $88 500 per year to trap, and has a trap efficacy of 0.6, then the cost-effective estimate of fully protecting the same area with trapping is estimated to cost about $147 500 per year (see Fig. 1a,b). The same applies to the cost of trapping required to achieve the rates of increase in skink populations (scaled to 1.0) observed inside a fully protected exclusion fence.

Sensitivity analyses

Sensitivity analyses were used to account for uncertainty in parameter values, and to identify parameters that have the greatest impact on cost-effectiveness. This was achieved by changing the parameter values of fence cost, fence longevity, fence maintenance cost, trap cost, trap maintenance cost, trap buffer width, discount rate, and efficacy of each method (values in Table 1b–q), and re-estimating NPV and cost-effectiveness. For simplicity, interactions between these adjusted parameter values were not assessed. Changing one parameter sometimes required changing another. For example, if the trap buffer width was extended, efficacy had to be increased according to its effect on further reducing the rate of predator reinvasion. Conversely, if the buffer width was reduced, the efficacy was reduced. Where necessary, changes were based on interpolation or extrapolation of observed predator trap rates from those observed at known buffer widths (see Table 2). The other simultaneous

Table 1. Typical parameter values (row 'a') used to model costs and cost-effectiveness of an exclusion fence, a leaky fence and trapping

Control option	Exclusion fence ($ per metre)	Leaky fence ($ per metre)	Leaky fence trap buffer (m)	Leaky fence efficacy	Fence replacement frequency (years)	Fence maintenance (%)	Trap maintenance ($ per trap per year)	Trap ($ per trap)	Trap buffer (m)	Trap efficacy	Discount rate (%)
a. Baseline	250	120	0	0.926	25	4	300	60	1500	0.600	8
b. Low-cost exclusion fence	200	120	0	0.926	25	4	300	60	1500	0.600	8
c. High-cost exclusion fence	350	120	0	0.926	25	4	300	60	1500	0.600	8
d. Low-cost leaky fence	250	100	0	0.926	25	4	300	60	1500	0.600	8
e. High-cost leaky fence	250	150	0	0.926	25	4	300	60	1500	0.600	8
f. Leaky fence with trap buffer	250	120	200	0.935	25	4	300	60	1500	0.600	8
g. Low leaky fence efficacy	250	120	0	0.800	25	4	300	60	1500	0.600	8
h. High-longevity fence	250	120	0	0.926	50	4	300	60	1500	0.600	8
i. Low-cost fence maintenance	250	120	0	0.926	25	2	300	60	1500	0.600	8
j. Low-cost trap maintenance	250	120	0	0.926	25	4	100	60	1500	0.600	8
k. High-cost trap maintenance	250	120	0	0.926	25	4	500	60	1500	0.600	8
l. High-cost trap (low maintenance)	250	120	0	0.926	25	4	100	150	1500	0.600	8
m. Narrow trap buffer	250	120	0	0.926	25	4	300	60	500	0.263	8
n. Wide trap buffer	250	120	0	0.926	25	4	300	60	2500	0.783	8
o. High trap efficacy	250	120	0	0.926	25	4	300	60	1500	0.700	8
p. Low discount rate	250	120	0	0.926	25	4	300	60	1500	0.600	4
q. High discount rate	250	120	0	0.926	25	4	300	60	1500	0.600	12

Parameter values used for sensitivity analyses are in rows 'b–q' (parameters that differ from baseline values in row 'a' are shaded). Efficacies are odds ratios based on predator trap rates (see Table 2). Note some parameter changes necessitated changes to another parameter (i.e. a 200-m trap buffer improves a leaky fence efficacy; a high-cost trap requires lower maintenance costs; and altering the trap buffer alters trap efficacy in the core area). The baseline trap maintenance cost of $300 per trap per year is based on 400 traps over 2100 ha, therefore equating to $60 ha^{-1} year^{-1} ($100 per trap per year = $20 ha^{-1} year^{-1}, and $500 per trap per year = $100 ha^{-1} year^{-1}). A low-cost trap is not presented because traps are unlikely to ever be cheaper than the baseline cost.

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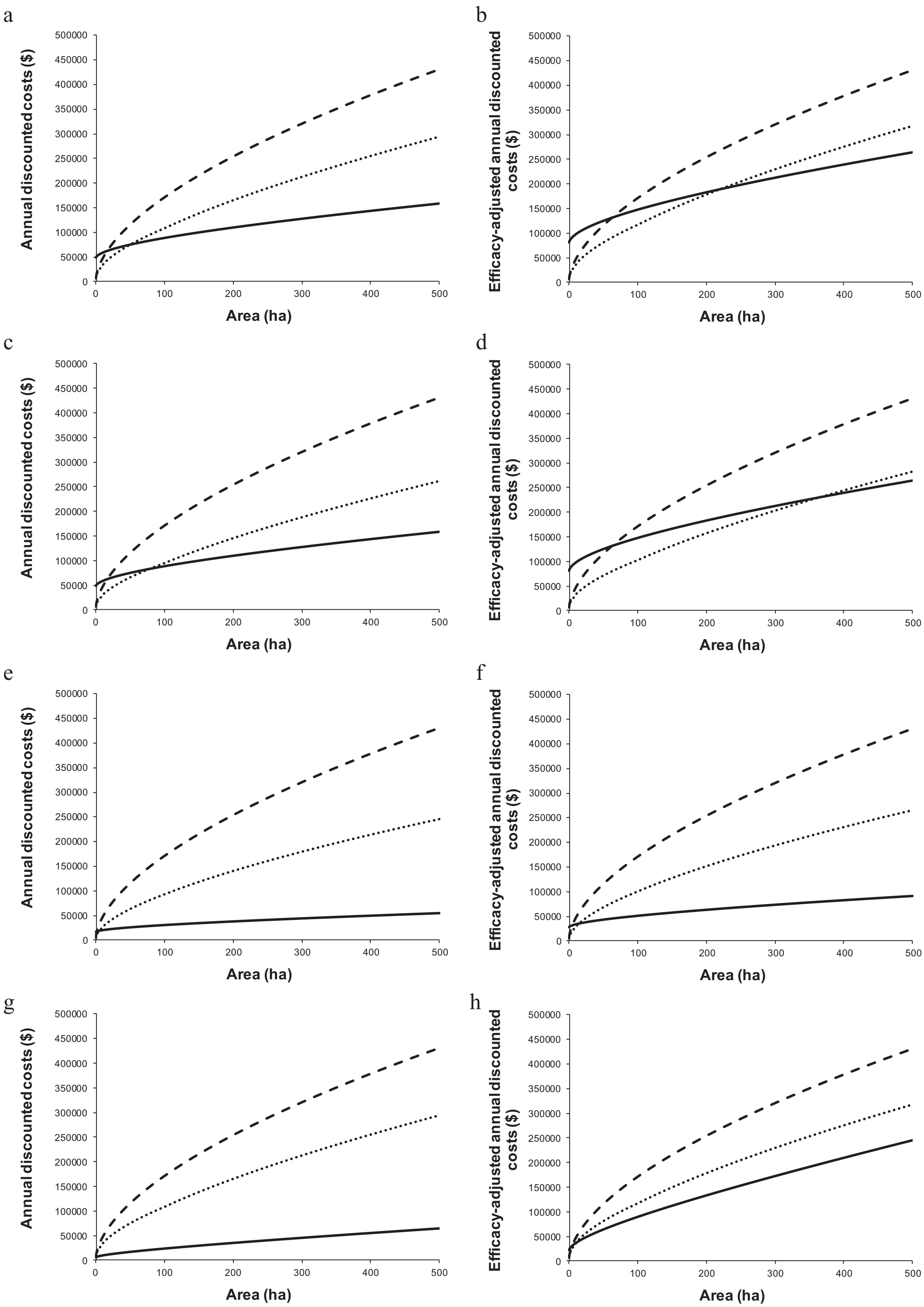

Fig. 1. Discounted annual costs (NZ$), and costs adjusted for efficacy based on predator odds ratio, of an exclusion fence (dashed line), a leaky fence (dotted line) and trapping (solid line), plotted against area protected using baseline parameter values (a,b) and examples of outputs from sensitivity analyses using a low-cost leaky fence (c,d), low trap maintenance costs (e,f) and a narrow trap buffer (g,h).

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Table 2. Odds ratios, or relative probabilities, derived from best-fitting models (based on Akaike's information criteria) of observed predator trap rates at various trap buffer depths, and inside and outside a leaky fence

Control option	Buffer depth (m)	Predator trap rate (per 100 trap-nights)	Odds ratio in predator trap rate	Efficacy
Trapping (Macraes Flat)	0	1.111	1.000	–
	200	1.011	0.885	0.115
	500	0.861	0.737	0.263
	1500	0.361	0.400	0.600
	2500	–	0.217	0.783
Leaky fence (Burwood Bush)				
No trap buffer	Outside fence	0.384	1.000	–
	Inside fence	0.028	0.074	0.926
Trap buffer	200 m outside fence	–	1.000†	–
	0 m outside fence	–	0.885‡	–
	Inside fence	–	0.065§	0.935

Efficacy is the difference in odds ratio from 1.0 (unmanaged predators). The core of the Macraes Flat trapping operation is approximately 1500 m from the edge, so the odds ratio for the 2500-m buffer depth is an extrapolation beyond the data. Odd ratios for the buffer applied to the leaky fence are inferred from other data indicated. †Assumed equivalent to odds ratio observed on fence line without a buffer. ‡Predicted from proportional decline in odds ratio observed 200 m inside trap grid at Macraes Flat. §Predicted from proportional difference observed inside and outside a leaky fence without a trap buffer (i.e. = 0.885×0.074).

Table 3. Examples of discounted annual costs of each control option as a function of area protected using the baseline parameter values in Table 1

	Control option		
Area (ha)	Exclusion fence	Leaky fence	Trapping
1	\$13 274	\$11 275	\$50 335
10	\$46 588	\$32 326	\$58 533
100	\$170 923	\$108 102	\$88 526
1000	\$646 404	\$462 990	\$224 060

parameter change was a reduction in trap maintenance costs for more expensive trap types that use long-life lures and therefore require less frequent checking.

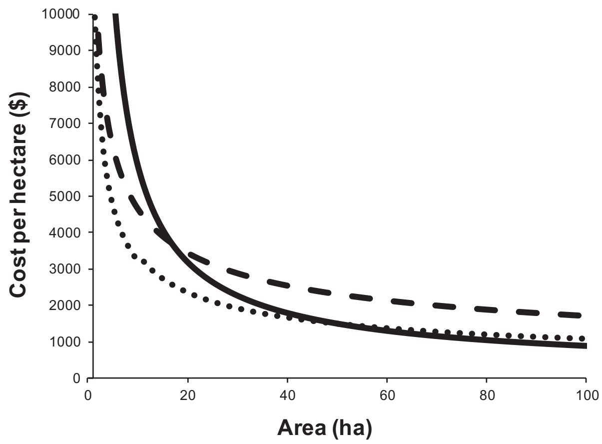

Fig. 2. Annual discounted costs (NZ\$) per hectare of an exclusion fence (dashed line), a leaky fence (dotted line) and trapping (solid line), as a function of area protected.

RESULTS

Discounted baseline costs

The discounted annual costs predicted from the model for an exclusion fence, a leaky fence, and trapping for areas up to 500 ha are shown in Figure 1 and Table 3. The cost of protecting 100 ha, for example, required \$170 923 per year for an exclusion fence, \$108 102 for a leaky fence, and \$88 526 for trapping, using the typical baseline parameter values in Table 1a. The rate at which costs increased with increasing area differed between management options, leading to crossover points where one option became cheaper than another for a given area. The model showed that an exclusion fence was the cheapest option only for areas below 0.25 ha (Table 4a). A leaky fence was the cheapest method for areas between 0.5 and 50 ha, and trapping was the cheapest method for areas greater than 50 ha.

As expected, costs per hectare gradually increased with decreasing area, but costs escalated dramatically below approximately 20 ha (Fig. 2). The cost of protecting 100 ha, for example, was \$885–\$1709 ha^{-1} $year^{-1}$, compared with \$3233–\$5853 ha^{-1} $year^{-1}$ for 10 ha.

The model was also used to identify the management option that covered the largest area possible within a set budget. A \$200 000 annual discounted

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Table 4. Areas (ha) for which each control option was the cheapest (expressed as total undiscounted costs and annual discounted costs) or most cost-effective [discounted costs/efficacy (predator odds ratio)] over a 50-year period

	Undiscounted costs			Annualized net present value			Cost-effectiveness		
Control option	Exclusion fence	Leaky fence	Trapping	Exclusion fence	Leaky fence	Trapping	Exclusion fence	Leaky fence	Trapping
a. Baseline	≤0.75	1–90	≥91	≤0.25	0.5–50	≥51	≤0.5	0.75–219	≥220
b. Low-cost exclusion fence	≤6	7–90	≥91	≤2	3–50	≥51	≤5	6–219	≥220
c. High-cost exclusion fence	never	≤90	≥91	never	≤50	≥51	never	≤219	≥220
d. Low-cost leaky fence	≤0.5	0.75–135	≥136	≤0.25	0.5–78	≥79	≤0.25	0.5–364	≥365
e. High-cost leaky fence	≤3	4–51	≥52	≤0.75	1–30	≥31	≤2	3–122	≥123
f. Leaky fence with trap buffer	≤2	3–71	≥72	≤0.75	1–42	≥43	≤1	2–192	≥193
g. Low leaky fence efficacy	na	na	na	na	na	na	≤2	3–131	≥132
h. High-longevity fence	≤0.5	0.75–343	≥344	≤0.5	0.75–64	≥65	≤0.5	0.75–297	≥298
i. Low-cost fence maintenance	≤2	3–146	≥147	≤0.5	0.75–73	≥74	≤0.75	1–342	≥343
j. Low-cost trap maintenance	never	≤8	≥9	never	≤5	≥6	never	≤14	≥15
k. High-cost trap maintenance	≤6	7–292	≥293	≤2	3–171	≥172	≤4	5–1449	≥1450
l. High-cost trap (low maintenance)	never	≤8	≥9	never	≤6	≥7	never	≤16	≥17
m. Narrow trap buffer	≤0.25	never	≥0.5	never	never	always	≤0.5	0.75–10	≥11
n. Wide trap buffer	≤0.75	1–898	≥899	≤0.25	0.5–499	≥500	≤0.5	0.75–901	≥902
o. High trap efficacy	na	na	na	na	na	na	≤0.5	0.75–128	≥129
p. Low discount rate	≤0.75	1–90	≥91	≤0.5	0.75–76	≥77	≤0.75	1–368	≥369
q. High discount rate	≤0.75	1–90	≥91	≤0.25	0.5–33	≥34	≤0.25	0.5–134	≥135

Predator odds ratios are taken from Table 2. Typical baseline parameters yielded results in row a, and variations in parameter values yielded results in rows 'b–q'. We used areas in 0.25-ha increments up to 1 ha, and in 1-ha increments up to 4000 ha. 'always', always cheapest or most cost-effective option for any area; na, not applicable; 'Never', never the cheapest or most cost-effective option for any area.

budget, for example, covered 132 ha with an exclusion fence, 272 ha with a leaky fence, and 807 ha with trapping (Fig. 1a).

Cost-effectiveness based on predator trap-catch

Leaky fences were more effective than trapping at reducing predator trap rates. At Burwood Bush, the trap rate outside leaky fences was 0.384 per 100 TN, compared with 0.028 per 100 TN inside. At Macraes Flat, the trap rate on the edge of the trap grid was 1.111 per 100 TN, compared with 0.361 per 100 TN 1500 m inside the grid edge (Table 2). The exclusion-fenced areas at Macraes Flat were free of mammalian predators, apart from the occasional incursion of mice.

Discounted costs adjusted for efficacy for areas up to 500 ha are shown in Figure 1. The model showed that an exclusion fence was the most cost-effective option of the three methods tested only for areas < 0.5 ha (Table 4a). A leaky fence was the most cost-effective method for areas between 0.75 and 219 ha, and trapping was the most cost-effective method for areas > 219 ha.

Sensitivity analyses

The parameter values used in the sensitivity analysis are shown in Table 1b–q. When the cost of an exclusion fence was reduced from \$250 to \$200 m^{-1}, the range over which an exclusion fence was the most cost-effective method increased from areas up to 0.5 ha to areas up to 5 ha (Table 4b). Increasing the cost to \$350 m^{-1} rendered an exclusion fence the least cost-effective option for any area (Table 4c).

Reducing the cost of a leaky fence from \$120 to \$100 m^{-1} nearly doubled its range as the cheapest method from 0.5–50 ha to 0.5–78 ha, and extended its cost-effective range from 0.75–219 ha to 0.5–364 ha (Table 4d). Thus a 17% reduction in cost returned a 66% increase in cost-effective range for this method. Increasing the cost to \$150 m^{-1} nearly halved its range as the cheapest method to 1–30 ha, and reduced its cost-effective range to 3–122 ha (Table 4e). The extra cost of safeguarding a leaky fence with a modest 200-m-wide trap buffer yielded only a marginal increase in efficacy (0.926 to 0.935, Table 2). Therefore, the buffer actually reduced its cost-effective range by 12% (Table 4f).

Increasing a fence's longevity or reducing its maintenance costs (as might be expected in a more benign climate or with improvements in fence design) increased the utility of a leaky fence more than for an exclusion fence. Doubling longevity from 25 to 50 years did not change the cost-effective range of an exclusion fence, but it did increase the cost-effective range of a leaky fence by 78 ha (to 0.75–297 ha, Table 4h). Halving fence maintenance costs had a similar effect in that the cost-effective range of an exclusion fence increased by only 0.25 ha, but that of a leaky fence by 123 ha (to 1–342 ha, Table 4i) or by 56%.

The cost-effectiveness of trapping was highly sensitive to the cost of checking and re-baiting traps.

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Long-life lures have the potential to substantially reduce these costs. Assuming trap maintenance costs are reduced by two-thirds (from \$300 to \$100 per trap per year), the area over which trapping was the most cost-effective option increased from areas > 220 ha to areas > 15 ha (Table 4j). Reducing the efficacy of trapping with long-life lures by 20% (a possibility given they might be less attractive than some fresh bait types) had little impact because the expanded cost-effective range was largely retained (i.e. areas above 15 ha with typical trap efficacy, compared with areas above 27 ha with reduced efficacy; result not shown in Table 4). Increasing trap maintenance costs (from \$300 to \$500 per trap per year), on the other hand, dramatically reduced the cost-effective range of trapping to areas > 1450 ha, which in turn markedly expanded the range of a leaky fence (Table 4k).

Self-resetting traps that are currently undergoing development rely on long-life lures to make them effective at catching multiple individuals over a period of time. We looked at whether their greater cost (assuming 2.5 times that of conventional traps) would offset the utility of long-life lures. The model showed this not to be the case because the cost-effective range of trapping with self-resetting traps and long-life lures was still very large (i.e. areas greater than 17 ha) (Table 4l).

Reducing the width of the trap buffer from 1500 to 500 m had a huge effect on the utility of trapping. Trapping became the cheapest method for all areas (Table 4m), and despite more than a 50% reduction in efficacy (0.600–0.263, Table 2), trapping still remained the most cost-effective method for areas greater than 11 ha. Increasing the buffer width to 2500 m, on the other hand, increased costs more than it increased efficacy, thereby reducing its cost-effective range substantially (Table 4n). Buffer widths greater than 3500 m rendered trapping the most costly and least cost-effective option (results not shown here).

The efficacies of trapping and a leaky fence were altered, without adjusting other parameters, to recognize the inevitable variation in control effectiveness between different projects and ecological systems. Cost-effectiveness was sensitive to these adjustments. The efficacy values observed for the leaky fences in this study were arguably quite high compared with most leaky fences. When reduced from the observed 0.926 to 0.800, its cost-effective range declined from 0.75–219 ha to 3–131 ha (Table 4g). Conversely, the efficacy values observed for trapping in this study were arguably low compared with most trapping regimes. When increased from the observed 0.6 to 0.7, its cost-effective range increased from areas above 220 ha to areas above 129 ha (Table 4o).

Lowering the annual discount rate from 8% to 4% increased the cost-effective range of a leaky fence from 0.75–219 ha to 1–368 ha (Table 4p). Increasing the discount rate to 12% per annum reduced the range to 0.5–134 ha (Table 4q).

Efficacy based on skink population recovery

We used observed rates of increase of skink populations as a measure of ecological efficacy of trapping and an exclusion fence (no such data are available for leaky fences). Rates for both grand and Otago skinks were highest inside the exclusion fences, lower outside the fences but deep inside the trapping grid (1500 m from edge), and lower again towards the edge of the grid (500 m from edge – grand skinks only; no Otago skink populations were monitored at this distance) (Table 5). Rates of increase were higher for Otago skinks than for grand skinks, but overall, the analysis yielded very similar outcomes to the efficacy measures based on predator trap-catch (Table 6). Because leaky fences were not included in this analysis, the cost-effective range of an exclusion fence was now greater. Using baseline costs, an exclusion fence was more cost-effective than trapping for areas up to 56 ha for grand skinks, and for areas up to 79 ha for Otago skinks – thresholds that are very similar to that (up to 62 ha) based on residual predator abundances. The most noticeable outcome from the sensitivity analysis of an exclusion fence versus trapping in this case is that if trap maintenance costs are high, an exclusion fence was the more cost-effective method for areas up to 420 ha for recovery of grand skinks, and for all areas for Otago skinks.

DISCUSSION

A key question posed by Scofield *et al.* (2011) is whether investing more in infrastructure that requires relatively low maintenance is a cheaper or more cost-effective strategy for protecting biodiversity in the long term than spending less on infrastructure up-front, but more on ongoing maintenance. Our findings clearly support the latter. Compared with trapping and a leaky fence, an exclusion fence is a high capital, low maintenance option that is the most expensive and least cost-effective method for practically all areas, regardless of the parameter values we used. Its utility as the most cost-effective option applied only to very small areas (e.g. for seabird colonies or invertebrate populations). The utility of the other methods were scale-dependent. Small- to medium-sized areas were best protected with a leaky fence, and larger areas were best protected by trapping. The average area currently protected by enclosed exclusion fences in New Zealand is 212 ha (minimum 0.3 ha, maximum 3330 ha) (Burns *et al.* 2012). This average drops to

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Table 5. Annual abundance estimates of grand (N_{Grand}) and Otago (N_{Otago}) skinks under three management regimes at Macraes Flat (see Reardon *et al.* 2012 for details)

Control option	Year	N_{Grand}	Ln(N_{Grand})	r_{Grand}	Efficacy$_{Grand}$	N_{Otago}	Ln(N_{Otago})	r_{Otago}	Efficacy$_{Otago}$
Full exclusion fence	2006	65.80	4.186620			59.56	4.086984		
	2007	78.83	4.367294			88.00	4.477337		
	2008	85.49	4.448399			105.28	4.656623		
	2009	104.71	4.651195			148.25	4.998900		
	2010	124.19	4.821813			172.06	5.147843		
	2011	149.24	5.005556			214.25	5.367144		
	2012	172.50	5.150397	0.1614	1.0000	247.99	5.513388	0.2355	1.0000
1500 m inside edge of trapping grid	2006	32.17	3.471034			38.28	3.644928		
	2007	36.51	3.597586			56.41	4.032646		
	2008	48.45	3.880532			75.03	4.317888		
	2009	49.32	3.898330			90.07	4.500587		
	2010	44.14	3.787366			98.66	4.591680		
	2011	52.99	3.970103			92.00	4.521789		
	2012	66.50	4.197202	0.1005	0.6227	83.47	4.424487	0.1307	0.5550
500 m inside edge of trapping grid	2006	128.46	4.855618			–	–		
	2007	138.24	4.928991			–	–		
	2008	140.31	4.943854			–	–		
	2009	134.85	4.904163			–	–		
	2010	134.93	4.904756			–	–		
	2011	150.30	5.012633			–	–		
	2012	141.91	4.955193	0.0153	0.0948	–	–	–	–

'r' is the mean exponential rate of increase over 6 years for each skink species derived by log-transforming abundance estimates and calculating the slope of fitted linear regression. Efficacy is the rate of increase expressed as a proportion of the rate inside a full exclusion fence. No Otago skink populations were monitored 500 m inside the edge of the trapping grid.

Table 6. Areas (ha) for which an exclusion fence or trapping is the most cost-effective method based on observed rates of increase of grand and Otago skink populations over 6 years (see Table 5) and discounted management costs

	Cost-effectiveness (grand skink rates of increase)		Cost-effectiveness (Otago skink rates of increase)		Cost-effectiveness (predator odds ratio)	
Control option	Full fence	Trapping	Full fence	Trapping	Full fence	Trapping
Baseline	≤56	≥57	≤79	≥80	≤62	≥63
Low-cost full fence	≤111	≥112	≤171	≥172	≤127	≥128
High-cost full fence	≤23	≥24	≤31	≥32	≤25	≥26
High-longevity fence	≤73	≥74	≤107	≥108	≤82	≥83
Low-cost fence maintenance	≤90	≥91	≤134	≥135	≤102	≥103
High-cost trap (low maintenance)	≤5	≥6	≤6	≥7	≤5	≥6
Low-cost trap maintenance	≤4	≥5	≤5	≥6	≤4	≥5
High-cost trap maintenance	≤420	≥421	always	never	≤562	≥563
Narrow trap buffer	always	never	–	–	≤4	≥5
Wide trap buffer	–	–	–	–	≤300	≥301
High trap efficacy	–	–	–	–	≤40	≥41
Low discount rate	≤95	≥96	≤143	≥144	≤107	≥108
High discount rate	≤34	≥35	≤47	≥48	≤38	≥39

No skink data were available from a leaky fence, from an extra wide trap buffer, or in the case of Otago skinks from a narrow trap buffer. Cost-effectiveness based on predator odds ratio is shown for comparison, based on the same analysis as for Table 4 (the thresholds from this analysis differ to those in Table 4 because the leaky-fence option is removed in order to compare results with skinks).

58 ha if the maximum area is omitted. Our model shows that most (90%) of these areas could be more cheaply and cost-effectively protected with either a leaky fence or with trapping, assuming the baseline costs used (this reduces to 70% for a low-cost exclusion fence). Therefore, if price or cost-effectiveness is important in decision making, an exclusion fence is a poor choice for controlling predators across most

restoration scales. This conclusion, however, is based on efficacy measures derived from predator trap rates in two grassland ecosystems, and from rates of recovery of grand and Otago skink populations. Extrapolating the results to other ecosystems, to other taxonomic groups (especially groups that require close to zero predation), or indeed to different fence or trapping designs to those tested here should therefore be done with caution. We stress, however, that managers at least undertake this sort of analysis *a priori* for their systems, revise outcomes as projects proceed, and ultimately disseminate information for others to use. A key requirement here is understanding the level of pest control and the residual abundance of critical pests required for persistence of indigenous fauna. This is sadly lacking in many areas of vertebrate pest management.

The observed rates of increase of grand and Otago skink populations provided an independent check of predator trap-catch as a measure of efficacy, and allowed cost-effectiveness of an exclusion fence and trapping to be expressed in ecological terms (as implored by Scofield *et al.* 2011). We were surprised by the similarity in the results, however, further work is required to overcome some experimental design issues at Macraes Flat concerning low replication and potentially confounding site effects. Also, we recognize that rates of increase over 6 years are an over-simplification of trends over the 50-year time frame for which the management costs are modelled. Our estimates of 'ecological' cost-effectiveness, therefore, must be viewed within this context.

Our general conclusion about exclusion fences is contrary to Clapperton and Day's (2001) cost comparison of an exclusion fence with the cost of trapping and poisoning. They concluded that a fence was a cheaper option for very large areas (>5000 ha), and perhaps also for areas between 100 and 1000 ha. However, Clapperton and Day (2001) used very low fence costs by today's standards (only \$50–85 m^{-1}), no buffer was included in the trapping, and costs were not discounted over the life of the fence.

Reducing the capital or maintenance costs of fences, or increasing fence longevity, increased the cost-effective range of leaky fences even further (but hardly changed that of exclusion fences). While the results for a leaky fence look very promising, the Burwood Bush operation was not designed to test their efficacy. For example, leg-hold traps, which are better than other trap types at catching cats, were present only outside the fence and not inside (because they can kill takahē). This may have inflated the true effectiveness of a leaky fence at excluding cats. The results were reasonably sensitive to the efficacy values used – reducing the efficacy of a leaky fence from 0.926 to 0.800 reduced its cost-effective range by 41%. Therefore, it may be premature to endorse leaky fences at this point until more robust testing is completed, including different designs. Purpose-designed leaky fences have not been adopted widely to date in New Zealand compared with other methods. In Australia, however, such designs are commonly used because they adequately exclude the key threats (cats and foxes) (Moseby & Read 2006; Dickman 2012).

The model revealed a significant increase in cost-effectiveness of trapping with reductions in trap maintenance costs. If long-life lures prove effective at catching predators, they will allow less frequent checking of traps (assuming use of kill-traps which do not require daily checks) and therefore substantial cost savings. As for self-resetting traps, trap saturation is an uncommon problem with pest control programmes, and so the utility of self-resetting traps lies primarily in the cost savings of the long-life lures they rely on. The model suggested that even with the greater capital expense of these traps, the savings gained by less frequent checking makes them more cost-effective than conventional traps and lures, even if some reduction in efficacy is assumed. Long-life lures and self-resetting traps are neither fully developed nor proven yet, so any endorsement is premature until they are more fully tested.

The density of traps used at Macraes Flat was 0.2 per hectare. While this is quite high compared with some trapping regimes in New Zealand, other operations use far greater densities (up to about 1.0 trap per hectare), especially those targeting rats in forest ecosystems. Our model showed (results not given here) that the additional cost of deploying one trap per hectare is so high that trapping was never more cost-effective than a fence, regardless of the increase in trap efficacy. Maintaining traps at one trap per hectare to protect large landscapes with sufficient buffer width requires major commitment of resources.

The model showed that reducing the trap buffer width from 1500 m to 500 m significantly increased the cost-effectiveness of trapping, despite the ensuing reduction in efficacy (although it is questionable whether efficacy of 0.263 will provide any protection for at-risk species). A 1500-m-wide buffer represents 74% on average of the total area trapped for areas up to 4000 ha. Therefore, reducing the buffer width has substantial savings. Increasing it to 2500 m had the opposite effect, and buffers wider than 3500 m rendered trapping the most costly and least cost-effective option. Even a 1500-m-wide trap buffer will be difficult to achieve in areas surrounded by private land unless full cooperation by landholders can be sustained in the long term. Similarly, the model showed it is not worthwhile adding a 200-m-wide trap buffer to a leaky fence because the benefit accrued is less than the cost.

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Given limited budgets for research and development, it is useful to consider which of the above technological advances are most worthwhile pursuing. For leaky fences, low cost designs returned the greatest gains in cost-effective range, and for trapping, devices that require low maintenance returned the greatest gains (Table 4). Technological advances that reduce the capital or maintenance cost of exclusion fences yielded little gain.

There are potential biases in the predator trap-catch data we used to assign efficacy. First, these data did not include mice and introduced herbivores that are usually present inside leaky fences and trapping grids. Mice are known to negatively affect a range of species (St Clair 2011; Norbury *et al.* 2014), and introduced herbivores can have negative effects on floristic values. Second, pooling trap-rate data across predator species assumes equivalent impact between species. Although hedgehogs negatively affect some indigenous biodiversity in New Zealand (Jones *et al.* 2013), they tend to dominate predator captures in non-forest ecosystems, and by doing so potentially overinflate efficacies derived from trap-catch data. To some extent, the sensitivity analysis using altered efficacy values allows for these potential biases.

Two Australian studies looked at cost-effectiveness of predator control. Bode and Wintle (2010) reported a procedure for optimizing fence design and length based on a benefit–cost analysis of variable costs, variable probabilities of fences being breached by predators, and the probability of population persistence for a species of an Australian mammal. While this is a different analytical approach to ours, we have effectively done the same thing because we used predator gradients, rather than probabilities of breach, and used observed rates of population increase (of skinks) rather than population persistence. Bode and Wintle's (2010) approach identified the minimum area that achieved population persistence. Our approach does not assume a minimum area, but instead allows area to vary according to whatever is deemed suitable by managers within the constraints they face, and identifies the most cost-effective method for that area. For grand and Otago skinks, at least, this is appropriate because both species appear capable of persisting at very low densities, often in small specialized remnant habitats where few other viable options are available. Therefore, deciding on the most cost-effective method for a given area is more useful in our case than deciding on an area that maximizes benefit. Baxter *et al.'s* (2007) study addressed the more strategic question of whether it is more cost-effective to eradicate or suppress predator densities. They concluded that while eradication yielded the highest expected minimum prey population size, suppressing predators once their densities reached an upper threshold level was a more cost-effective strategy.

We omitted analysis of ground or aerial toxin applications for pest control because they were not components of sustained management in the projects we analysed. Given that aerial toxin delivery is widely acknowledged as a cost-effective pest control method (Walker 1997; Powlesland *et al.* 1999), extending this analysis to include such methods is an essential next step if a bio-economic approach to pest management is to be applied at a broad scale. Similarly, the utility of fences will be quite different for areas that are protected by natural barriers, such as peninsulas.

Our study provides an economic basis as a starting point for decision making, but ultimately, decisions are also influenced by non-economic issues (Innes *et al.* 2012). For example, trapping has advantages of flexibility in time and space, and it can be integrated more easily with other land uses and has no visual impact on landscapes. Fences, on the other hand, have advantages of stopping or limiting pest immigration thereby allowing zero (or near zero) densities of all mammalian pest species for extended periods, which is required for indigenous species that are highly sensitive to predation. Fences inspire communities because they are a tangible achievement, and funders often prefer to fund capital items such as fences rather than wages for ongoing trapping or poisoning programmes. The key problem with fences is their limited scale of application. This has raised concerns about the potential for fences to enhance inbreeding and isolation of populations, thereby restricting evolutionary potential (Hayward & Kerley 2009).

Economics and cost-effectiveness are principal concerns for most managers and funders. Bode *et al.* (2012) provide useful arguments for why structured decision-making is important for conservation. It is important to stress that the results of our study have general application to broader biodiversity protection aspirations, but not necessarily to indigenous species that are highly sensitive to predation (e.g. saddleback, little spotted kiwi, greater bilby, rufous hare-wallaby) and only ever adequately protected on the mainland by exclusion fences. It is hoped our study at the very least encourages more bio-economical thinking in decision-making about pest control, and promotes greater focus on evidence-based conservation in general (Ferraro & Pattanayak 2006; Pullin & Knight 2009).

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