Valuing conservation benefits of disease control in wildlife: A choice experiment approach to bovine tuberculosis management in New Zealand's native forests

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Abstract

We assess the non-monetary environmental benefits that accrue incidentally in New Zealand (NZ) from pest management conducted primarily to control an animal disease, bovine tuberculosis (TB). TB is an infectious disease that is one of the world's most serious animal health problems and, in many parts of the developing world, still a major mortality risk for humans. The incidence of TB in New Zealand (NZ) farmed livestock has been reduced progressively over the last 20 years, largely due to extensive and sustained population control of the main wildlife reservoir of disease, the introduced brushtail possum. Possums are also major pests that threaten indigenous forest biodiversity, and so extensive possum control for TB mitigation also incidental benefits conservation, but the extent and public value of this benefit has yet to be quantified. We conducted a choice experiment survey of the NZ public in an effort to value the native forest biodiversity benefits of TB-related possum control. We find strong public support for conservation outcomes consequent to TB-possum control in public native forests. The public place substantial value on the most observable biodiversity benefits of TB possum control, such as improved forest canopies and presence of native birds. The benefits, costs and values of TB-possum control are discussed in relation to the future directives of NZ's TB control programme, which is headed toward first regional and then national level disease eradication.

Key words: New Zealand; bovine tuberculosis; possum control; non-market benefits; biodiversity; conservation values.

1. Introduction

Valuing the non-monetary environmental benefits of pest management conducted for commercial or human or animal health reasons is difficult and has rarely been attempted, but here we document an attempt to do so in the context of bovine tuberculosis management in New Zealand. Bovine tuberculosis (TB) is a chronic zoonotic disease of livestock that still poses a significant threat to livestock production and human health in many developing countries (Ayele et al., 2004). In developed countries, however, TB has mostly been eliminated from livestock by identifying and removing infected or potentially infected animals from livestock herds (Cousins, 2002). In some places, however, eradication is far more difficult because the disease has widely established in wildlife — in NZ's case, the brushtail possum (*Trichosurus vulpecula;* a small forest-dwelling marsupial introduced from Australia) has, since the 1960s, become the main wildlife reservoir of TB (Nugent et al., 2015). Possums (and in a few places, ferrets (*Mustela furo*)) are the only wildlife hosts able to independently sustain TB infection, and can re-infect cattle, therefore control or eradication of TB from livestock necessarily requires controlling or eradicating it from possums. Government-led efforts to eliminate TB from livestock were therefore expanded (in 1970s) to include lethal control of infected possum populations. This eventually evolved into a public-private partnership between the government and the livestock industries under a formal National Pest Management Plan for Bovine Tuberculosis (NPMP) that is implemented by a statutory agency (OSPRI/TBfree, formerly the Animal Health Board; Livingstone et al., 2015). Since the inception of the NPMP in 1994, TB-related possum control has been implemented over about 8 million ha (approx. 30% of NZ), and TB levels in livestock have fallen by more than 95% (Livingstone et al., 2015b). The NPMP was reviewed in 2014-15, and, as part of that, the cost of possum control was evaluated in relation to the value of not only the direct TB-related benefits but also of other indirect benefits (NZIER, 2015).

As part of that evaluation, this paper focuses on valuing the benefits to conservation from TB-related possum control. These benefits arise because possums, as an invasive species, are also major pests that directly threaten native forest biodiversity (as well as causing other damage in other spheres such as plantation forestry (Jacometti et al., 2007)). In addition, TB-possum control (usually by poisoning) within native forests also typically reduces densities of other invasive conservation pests such as rats and stoats, further reducing the overall threat to biodiversity (Didham et al., 2009; Byrom et al., 2016). Possum are arboreal. They feed mainly on leaves, flowers, and fruits of preferred trees and other plants nestlings (Nugent et al., 2000) and their browsing can cause or exacerbate forest canopy dieback (Nugent et al., 2000; Gormley et al., 2012) and reduce the abundance of preferred sub-canopy plant species. In addition, as occasional omnivores, they also eat insects, bird's eggs and nestlings and even carrion (Nugent et al., 2000), adding to the devastating effect of other introduced small mammal pests on NZs native fauna (Brown et al., 2015). The NZ public is deeply aware of these adverse impacts and almost universally sees possums and other non-native mammalian predators as pests to be exterminated (Russell, 2014). Because of those threats, particularly to indigenous biodiversity, the Department of Conservation (DOC), regional councils, and private conservation groups impose intensive possum control on many areas of public and private land, and would do so vastly more widely if they could afford it. Thus, the large amount of possum control undertaken for TB-related purposes produces co-benefits to conservation; especially where agencies and groups focussed on conservation of native forest biodiversity would like to see control imposed but cannot afford it. However, those co-benefits have been only partially quantified in biological terms (Byrom et al., 2016), and not valued at all in economic terms. Despite the substantial uncertainty about the exact nature and size of those co-benefits, the need for an economic valuation of them arose from the likelihood that on-going governmental funding (on behalf of the general public) of TB-related possum control would partly depend on the value of the ancillary benefits to conservation that it provides. Put simply, many New Zealanders are strongly aware of the damage that invasive alien pests (and weeds) cause in both productive and native ecosystems, and therefore desire action to be taken to reduce that damage (Russell 2014), and here we focus on determining how much they are willing to pay to mitigate part of that damage.

In this study we therefore aimed to quantify the economic value of the benefits to conservation of indigenous biodiversity in native forest ecosystems that flow from TB-possum control not previously available by employing a choice experiment survey of the NZ public's willingness to pay (WTP). This study adds to the limited empirical evidence base and also contributes to developing interdisciplinary approaches to evaluate pest management programmes by combining economic and biological measures of value (Laurila-Pant et al., 2015) to form an assessment of biodiversity outcomes that integrates natural and social science methods. To create a direct linkage between public preferences for biodiversity outcomes with assessment of possum control effectiveness and scale, our analysis relies on an approach that engages ecological expertise to characterise some key biodiversity attributes as readily understandable continuous measures of TB-possum control outcomes.

2. Methods and materials

2.1. Background to the use of a Choice Experiment approach

In face of ongoing invasive incursions, declining acceptability of some existing response methods, and intensifying land use, budgets for pest management are typically inadequate (Goldson et al., 2015). This drives the need for robust prioritisation systems, and Cost Benefit Analysis (CBA) has become a standard decision tool (Goldson et al., 2015). However, non-market benefits, such as improved environmental outcomes are difficult to monetise and so are usually ignored (Shwiff et al., 2013). Whilst perhaps secondary to commercial imperatives (Slaney et al., 2010), omission of these benefits may lead to significant undervaluation of response programmes (Holmes et al., 2009; Rosenberger et al., 2012). To overcome this, numerous studies have used non-market valuation (NMV) to estimate (for example) recreation values associated with forest resources (Riera et al., 2012), but there are few estimates of the non-market benefits from management of invasive species (Meldrum et al., 2013) or of public willingness to pay for protection and/or enhancement of forest biodiversity (Czajkowski et al., 2014; Giergiczny et al., 2015).

NZ's export markets value biodiversity as part of the 'clean and green' brand (Tait et al., 2016), and international tourists value the 'natural' experience which native biodiversity provides (Sun et al., 2015). The recreational opportunities and aesthetic benefits provided by native ecosystems combined with the uniqueness of NZ's indigenous biodiversity (because it evolved in the absence of any terrestrial mammals; Brown et al., 2015) has played a major role in forming cultural identity (Roberts et al., 2015). However, these benefits have rarely been quantified. Kerr and Cullen (1995) used a contingent valuation approach to show that protection of vulnerable rare species was, in that context, the most important benefit of possum control, and they estimated an annual mean WTP for possum control of $300 per adult. In another CV application, Yao et al. (2010) found households were WTP $42 and $82 annually to support public native tree planting programs on private and public land respectively. However, the validity and reliability of the contingent valuation approach has long been questioned, particularly for valuing abstract or complex phenomena (Diamond and Hausman, 1994).

However, choice experiments have relatively recently emerged as a more sophisticated non-market methodological approach that is considered capable of accounting for the complexity and abstractness of biodiversity concepts in valuation (Meyerhoff et al., 2009; Bartkowski et al., 2015, Haefele et al., 2016). In NZ, choice experiments have been applied to estimate values for native biodiversity outcomes within a planted forestry context (Yao et al., 2014). Globally, there have also been some TB-related uses of choice experiments (Bennett and Willis 2008; Bennett and Balcombe, 2012) but these are not directly relevant to TB management in NZ.

Choice experiments are based in Random Utility Theory in which a respondent's utility is decomposed into an observable deterministic part and an unobserved random component; and Lancaster's characteristics theory of value in which a good can be decomposed into its component attributes (Lancaster, 1966). This framework allows for preferences for the native forest good to be represented by the biodiversity attributes it contains, whilst econometrically accounting for unobserved influences on respondents utility not captured by the biodiversity attributes. This survey based method simulates a market in situations where no market exists. A good comprised of a bundle of attributes is offered at a given price, with respondents selecting their preferred combination of attributes and price (see Hensher et al. (2015) for substantive detail of the methodology). Responses are typically analysed within a probabilistic econometric framework to derive population estimates of changes in welfare for a substantive coverage. We also followed the guidance to best-practice in NMV of forest goods and services provided by Riera et al. (2012).

2.2. Choice experiment survey development and administration

We characterised a set of biodiversity attributes reflecting the adverse effects of possums in New Zealand's native forest, and used these to describe the conservation outcomes of various levels of TB-related possum control in such forests. This characterisation was undertaken primarily at workshops involving the research team and NZ's leading researchers in native forest conservation. Participants debated and eventually agreed on what biological changes in native forest ecosystems were likely to result from TB-possum control, and how those changes could be characterised in the simple terms required for public surveying. Four broad areas of conservation benefit were considered as the most relevant to TB-possum control in the context of a national survey, improvements in: a) forest canopy cover; b) the abundance of large native invertebrates; c) native birds; and d) within-forest plants. As already noted, possums (often in conjunction with other pests) can adversely affect all of these components of native forest biodiversity because they are arboreal omnivores (Nugent et al., 2000). To be able to offer a wide range of conservation outcomes that were dependent on the scale and intensity of TB-possum control and consequent outcomes, four scenarios were developed. The first involved little or no TB-possum control in native forest on public land (resulting in no additional protection above the background level already provided by DOC). The second involved periodic low-intensity control of possums alone, and the third involved more frequent high intensity possum control that also produced additional control of other small mammal pests (particularly rats). The fourth involved frequent possum control plus deliberate co-investment in more frequent control of rats and other pests.

The second and third scenarios were assumed to span the intensity of TB-possum control currently conducted in public native forest. The first scenario represents a major reduction in effort through either complete cessation of TB-possum control, or (more realistically) where TB-possum control (mostly on- or near-farm only) is undertaken on a non-orchestrated basis by industry and affected landowners (Animal Health Board, 2009),while the forth scenario represented an expansion of management effort above current levels.

In framing the different levels of conservation benefits arising under the four scenarios, we recognised that a crucially important design principle was the need to describe the benefits from TB-possum control *relative* to those delivered by DOC. DOC manages approx. 9m ha of Public Conservation Land (PCL). To achieve a cost-effective method for actively conserving a full array of NZ ecosystem types, DOC has ranked 850 high-priority ecosystem management units spanning about 3m ha of PCL (Leathwick et al., 2012; Leathwick and Wright, 2012), but is only able to implement pest control in a subset of these. There is substantial overlap between the areas requiring possum control under DOC's priorities and those that are a priority for TB-possum control. In 2013, TB possum control was undertaken on approx. 1.75m ha PCL, with approx. 0.6m ha within DOC priority areas.

Table 1 The four broad attributes of native forest biodiversity affected by possums (in conjunction with rats and predators), showing how we characterised and quantified (in broad approximation terms) the increasing levels of benefit the we presumed would result from increasing levels of possum and rat and predator control relative the levels under baseline management by DOC. Note that possums are primarily arboreal foliovores able to browse plants at all levels within a forest, but also omnivorously prey on large insects and birds (Nugent et al., 2000).

Native forest biodiversity attributes	No TBfree management No increase in protection above DOC level	TBfree management levels Increase in protection above DOC levels		
		TB-only possum control	Frequent TB possum and rat control	Frequent possum, rat and predator control
Health (foliar cover) of canopy tree species	**Heavy browse and substantial dieback** of vulnerable canopy species	**Most** TBfree managed forest with healthy unbrowsed trees. **100%** increase in protection above DOC level	**All** TBfree managed forest with healthy unbrowsed trees. **150%** increase in protection above DOC level	Same improvement (150%)
Abundance of large native invertebrates	All large native invertebrate populations **severely affected or eliminated**	**Some** possum-vulnerable large invertebrates partially protected but most still affected. **20%** increase in protection above DOC level	**Most** vulnerable large invertebrates well protected but a few still affected. **120%** increase in protection above DOC level	**All** large invertebrates protected in TBfree managed forest. **150%** increase in protection above DOC level
Abundance of native birds	All native birds threatened by possums **severely affected or eliminated**	**Some** possum-vulnerable native birds partially protected. **25%** increase in protection above DOC level	**Most** possum-vulnerable native birds protected. **100%** increase in protection above DOC level	**All** TBfree managed forest with healthy native bird populations. **150%** increase in protection above DOC level
Health of within-forest plants	All vulnerable within-forest plants **heavily defoliated, limiting regeneration**	**Some** but not all vulnerable within-forest plants protected **100%** increase in protection above DOC level	**All** TBfree managed forest with healthy unbrowsed within-forest plants **150%** increase in protection above DOC level	Same improvement (150%)
Annual tax contribution	$0	$25, $50, $75, $100		

For each of the four management scenarios, the levels of biodiversity outcomes were determined, and described relative to those that would otherwise be provided by DOC under the 'no TB-possum control' scenario (Table 1). This was intended to enable respondents to consider how TB-possum control benefits compared in scale and intensity to the conservation benefits that they already pay for (through taxes) for DOC's purpose-led management of biodiversity, providing respondents the ability to express their preference for benefits additional to those delivered by DOC. To help respondents assess the scale of TB-possum control activities relative to DOC's possum control activities, we graphically characterised possum control activities nationally in 2013 (Fig. 1) in order to highlight the much greater scale of TB-related control relative to level currently affordable by DOC

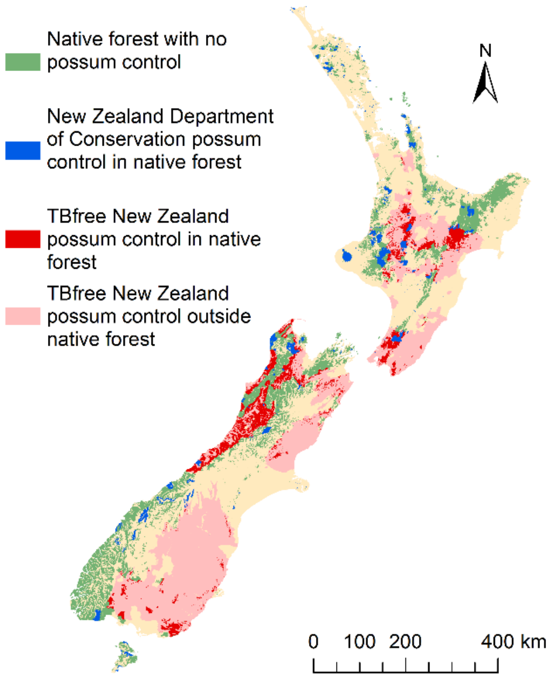

Fig. 1. Spatial extent of TBfree New Zealand Ltd and New Zealand Department of Conservation (DOC) possum control in New Zealand native forest. Note the area of native forest under TBFree New Zealand management (red) is substantially larger than the area in which possums are controlled by DOC (blue)

Twelve choice sets were constructed, each made up of three alternatives, employing a d_p-efficient fractional factorial design optimised for Multinomial Logit using Ngene™ (Bliemer et al., 2008). The design was blocked into two with each respondent presented with six choice sets (an example choice set is provided as Supplementary Material). This is a statistical efficiency approach that minimises the determinant of the asymptotic variance-covariance matrix with the aim to produce data that generates parameter estimates with as small as possible standard errors. Coefficient priors for generating the initial experimental design were derived from literature with this design used in a pilot study of 150 NZ residents using an online panel conducted in January 2014. Coefficient estimates derived from Multinomial Logit modelling of this data were used to update the experimental design applied to the remainder of the sample (n=663). Each choice task contained the 'No TB-possum management' outcomes, paired with two options depicting different levels of outcomes with management. The survey instrument comprised three sections, the first explored respondent's attitudes and experiences regarding native forest, the second presented the choice experiment, while the third contained demographic questions.

The first section of the survey contained five-point likert-scale questions used to explore the relative importance (very important, somewhat important, neutral, somewhat unimportant, not important) respondents placed on native forest providing habitat for native flora and fauna (the attributes valued in the choice experiment) against other aspects of value that the public derives from native forest including employment and recreation. (Fig. 2 shows the complete list of use categories presented to respondents). A further set of questions were used to explore the types of forest based activities respondents participated in during the previous twelve months (open response) and the frequency of participation in those activities (Fig. 3 shows the frequency category options presented). The full internet-based survey of NZ residents was conducted in February 2014 using a national database maintained by Research Now (www.researchnow.com). This facilitated a quota-based sampling approach by age, gender, education, occupation, income, household size, and location using NZ population level distributions (comparison of sample and population demographics presented in Supplementary Material)

2.3. Statistical analysis

To allow modelling of variation in individual preferences for biodiversity outcomes we fit a Random Parameter Logit Error Component (RPLEC) model to the data (Train, 2009). The error component specification is chosen as appropriate to accommodate correlation between the two management options conducting possum control versus the no possum management option in each choice set. We specify attribute parameters to randomly vary according to a normal distribution across respondents but remain constant across choices for the same respondent (Revelt and Train, 1998). Other distributions considered included triangular, uniform, and log-normal with the choice of normal distribution determined by model fit based on the Log-Likelihood function. To accommodate behavioural plausible heterogeneity in preferences towards the tax attribute, while ensuring meaningful WTP estimates, the cost parameter is specified as a constrained triangular distribution with mean equal to standard deviation (Hensher and Greene, 2015; Bliemer and Rose, 2013). The choice of cost parameter distribution is an econometric consideration based on the empirical distribution of the derived WTP estimates and ensures that the sign of the parameter estimate is behaviourally plausible throughout the entire population. Estimated choice probabilities for the RPLEC were simulated using Nlogit™5.0 based on 750 Shuffled Halton draws. When choosing their preferred option in each choice task, respondents may ignore some attributes and base their decisions on those remaining. This behaviour is commonly referred to as attribute non-attendance and can influence welfare estimates (Kragt, 2013). In a separate analysis we test for this influence using debriefing questions following each choice task (Carlsson et al., 2010).

3. Results and discussion

3.1 Patterns of response

A response rate of 15% was achieved, resulting in a total of 813 completed surveys being usable for the choice analysis generating 4,878 choice observations. Demographics did not depart from national Census survey data, except that the sample contained fewer than expected respondents with high school level qualifications only, and more with tertiary level qualifications (Supplementary Material). Examining responses to likert-scale questions, habitat for native flora and fauna was the most important use with 74% of respondents considering this use to be very important (Fig. 2). Commercial use was deemed to be the least important of the factors considered with just 22% of respondents considering providing employment opportunities as very important. However this type of use also generated the largest number of neutral responses, suggesting that the specific type of job creation may influence respondent support. Interestingly, respondents considered attracting tourism to be relatively less important in spite of NZ's native environment being a major reason for international visitors travelling to NZ. Overall, these results suggest that passive-use values are a more significant driver of importance to NZ residents (compared with direct-use activities), paralleling (for example) the high passive-use value placed on National Parks by the USA public (Haefele et al., 2016). This means that although many residents may not directly engage with native forests, they are still valued for the benefits they provide to the wider public, such as existence, bequest, and option values.

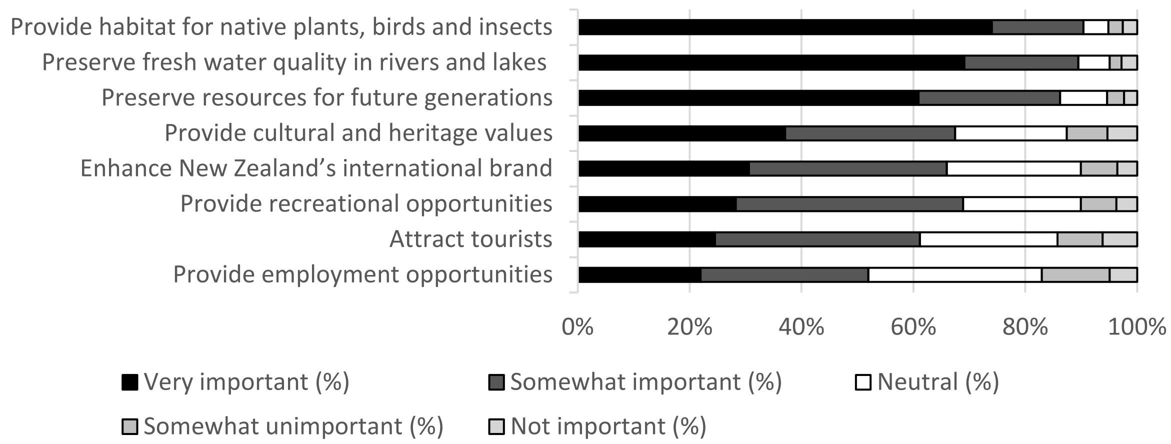

Fig. 2. Importance of native forest uses to survey respondents

A small majority of respondents (54%) had participated in at least one activity based in a native forest in the previous twelve months (Fig. 3). Hiking had the highest level of participation. Walking and hiking (also commonly known trekking) are closely related, with hiking generally defined as more demanding walking over terrain and distance. Few respondents undertook employment activities in native forest. The 'other' activities category comprised a diverse range of uses including sightseeing, bird watching, swimming and camping. The total sum of uses is greater than the sample size as some respondents participated in more than one activity. Although it appears the number of respondents engaging in activities is substantial, most do so infrequently. Most participants had engaged in activities only once or twice in a year (40%) and just 6% on a weekly basis. This pattern of engagement is consistent with native forests being generally distant from major populaces making access more difficult.

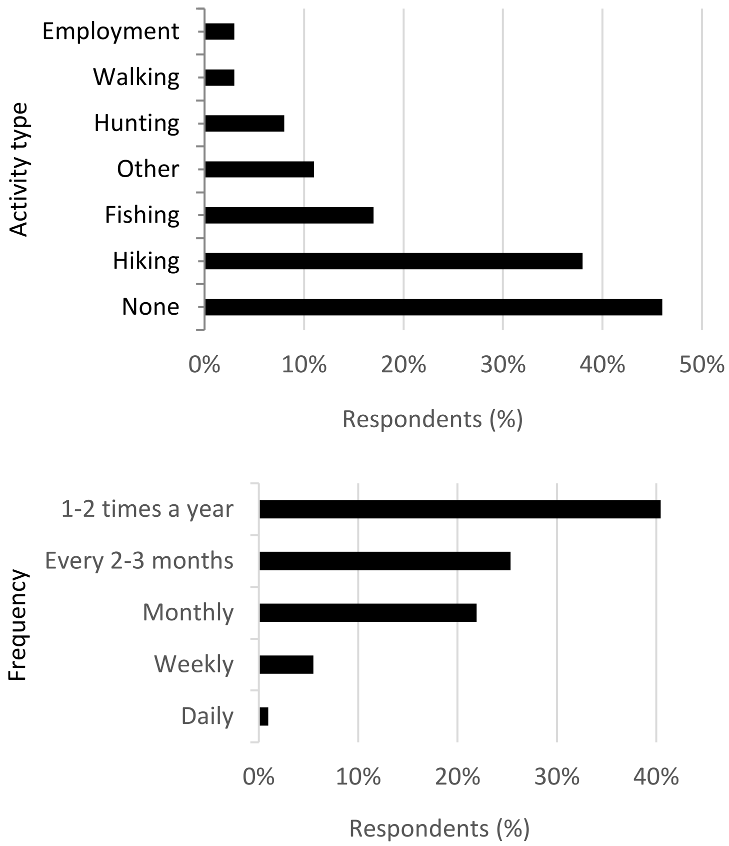

Fig. 3. Survey respondents' activity type and frequency in NZ native forests

Table 2

Random Parameter Logit Error Component Model Estimates

	Coeff. (st. err.)		St. Dev. (st. err.)	
Parameters in utility function				
ASC-No TBfree management option	-3.99***	(0.73)		
Important use as native habitat	1.01**	(0.05)		
Canopy tree species	2.14***	(0.31)	2.01***	(0.41)
Large native invertebrates	0.35***	(0.05)	0.01	(0.92)
Native birds	0.72***	(0.05)	0.49***	(0.09)
Within-forest plants	0.50***	(0.08)	0.02	(1.69)
Annual tax contribution	-0.99***	(0.73)	-0.99***	(0.01)
Heterogeneity in mean of random parameters				
Visits to native forest*Canopy tree species	0.005***	(0.001)		
Visits to native forest*Native birds	0.002***	(0.001)		
Standard deviation of latent random effects				
Expanded management options	4.39***	(0.61)		
Log likelihood	-3674			
McFadden Pseudo R^2	0.33			
AIC	7370			
Number of observations	4,878			

Note: ***, ** Significance at 1% and 5% level.

Attribute non-attendance analysis revealed that canopy tree species was ignored in 6% of choice tasks, native invertebrates 9%, native birds 6%, within-forest plants 8%, and tax contribution 18%. A restricted model specifying zero utility to ignored attributes was fitted (Kaye-Blake et al., 2009) and found to out-perform models not incorporating attribute non-attendance behaviour, and was therefore adopted in reporting (Table 2).

Biodiversity attributes are modelled in levels as percentage improvements in biodiversity outcomes in TBfree managed native forests (Table 2). All the TB-possum control attributes were highly statistically significant indicating that they were important factors in respondent's preferred management option. Respondents were more likely to choose a management option that had higher levels of protection for biodiversity outcomes, with changes in protection of canopy tree species having the largest influence, while they were less likely to choose options imposing greater tax contributions. Estimates of the standard deviation of parameter distributions for canopy tree species, native birds and tax are statistically significant indicating preferences heterogeneity, while preferences for improvements in large native invertebrates and within forest plants appear constant across the population. The relatively large standard deviation associated with canopy tree species shows substantive preference heterogeneity for improvements in this outcome indicating disutility for some individuals. We also explored heterogeneity in preferences by specifying the number of visits to native forests as the source of variation of the parameter mean across individuals.

Respondents who believed that native forests were important to 'provide habitat for native plants, birds and insects' (Fig. 2) were more likely to choose a management option with improved biodiversity outcomes (dummy variable = 1 if important or very important, 0 otherwise). An alternative specific constant (ASC) is specified indicating the status-quo 'No TBFree management' option (ASC=1 if SQ, 0 otherwise). The significant negative parameter estimated for the ASC indicates a relatively strong preference overall for TB-possum management that avoids the poorer outcomes associated with the 'No TB-possum management' option. However, 13% of respondents chose the 'No TB-possum management' option at least once over the six choice tasks presented to them; 4% of these respondents chose this option only once, while 3% chose this option in all choice tasks. None of the status-quo behaviour were identified as protest responses (Meyerhoff and Liebe, 2010) and all were included for analysis.

The significant standard deviation of the latent effects suggests there are sources of unobserved heterogeneity associated with the two management options (Scarpa et al., 2005). Respondent preferences for environmental improvements may be influenced by their spatial relationship to where those amenities might occur (Tait et al., 2012), so we tested for spatial or regional difference in respondents preferences, but found no evidence to support this possibility using data on the total amount of managed forest within a respondents region ($p > 0.1$) or the distance to the nearest managed forest ($p > 0.1$).

3.2. Willingness-to-pay estimates

The model parameters in Table 2 were used to estimate respondent's WTP for the biodiversity benefits generated indirectly from TBfree possum control in native forests. Marginal WTP was simulated from the unconditional parameter distribution accounting for significant preference heterogeneity in random parameters (Table 3).

Respondents were WTP most for improvements in canopy tree species. This may simply reflect that the greater visual impact of heavy tree defoliation by possums, relative to that of changes in the other three attributes. These WTP estimates are consistent with other relevant choice experiment studies. In Spain public WTP for a 1% increase in native forest has been valued at €1.4 (Hoyos et al., 2012), broadly matching our WTP per 1% of native tree canopy protection. Similarly, regeneration of deteriorated forest in Poland has been valued at €0.4 per 1% increase in area of forest regenerated (Czajkowski et al., 2009); and WTP for increases in forest conservation areas in Finland has been estimated at €4 per 1% increase in area (Lehtonen et al., 2003). In NZ, WTP for increases in native birds and insects in native forests from few to many has been estimated at $122 and $94 respectively (Kerr and Sharp, 2008). In a plantation forest context, WTP for an increase from 0.5% to 10% of forests where Kiwi calls are heard has been estimated at $28 (Yao et al., 2014). Although these comparisons vary over research contexts and design elements, they indicate that WTP estimated here are within the range recorded by others.

Table 3

Biodiversity attributes marginal willingness to pay

	Median WTP for each 1% increase in protection (New Zealand $/person/year)
Canopy tree species	2.02 (1.53 - 2.50)
Large native invertebrates	0.35 (0.29 - 0.42)
Native birds	0.72 (0.64 - 0.79)
Within-forest plants	0.51 (0.37 - 0.63)

Note: 5^{th} and 95^{th} percentiles in brackets.

To estimate the total national value placed on biodiversity benefits provided by TB-possum control, we construct a compensating surplus estimate. This takes into account variation between different types of native forest in the degree to which possum control produces the biodiversity benefits we depicted. This variation arises from the major differences in species composition between forest types and the strong feeding preferences of possum (Nugent et al., 2000) – some common forest types have canopies comprised almost entirely of trees such as the various beech (*Nothofagus*) species that are unpalatable to possums, hence those forest canopies are unaffected by possums and therefore do not change in response to possum control. Others, such as tawa (*Beilschmedia tawa*), have many more possum-palatable species in the canopy, so possum control produces the substantial improvement in canopy health that we depicted (Nugent el al., 2010, Gormley et al., 2012). However, possum control in both beech and tawa dominated forests is likely to benefit both birds and large invertebrates (Byrom et al., 2016). The compensating surplus estimate also needed to take into account differences in outcomes that depend on which control method was used. In most areas of native forest on PCL, TB-possum control is undertaken using an aerially distributed poison that also kills other small mammal conservation pests, but in some area the primary method is ground-based trapping which largely does not affect pest species other than possums, and therefore is unlikely to be as beneficial to birds and invertebrates (Byrom et al., 2016).

To account for these factors in the valuation, we combined spatial data on 25 forest classes defined in the Forest Service Mapping Series 6, an ecological survey of NZ's indigenous forests, with spatial data on aerial and ground control application (Ollivier, 2008). Delphi survey approaches have recently been employed within a similar context by Giergiczny et al. (2015) and this study employs a modified Delphi approach (Linstone and Turoff, 1975) in which expert pest managers and ecologists were engaged to assign a percentage improvement to each combination of forest type, control method, and biodiversity attribute[1]. This process estimated improvements of a) 54% in forest canopy cover b) 24% in the abundance of large native invertebrates c) 24% in native birds d) 49% in within-forest plants. These improvements combined yield a value of $NZ 156 ($132 - $179) per person annually relative to the magnitude of benefits achieved by DOC. If multiplied across the approx. number of taxpayers in NZ (2,773,911), total WTP would greatly exceed the amount of money actually spent on TB-possum control on all lands in recent years ($50-60m annually; Livingstone et al., 2015), and also the level of total spending on pest control by DOC. However, that estimate would not take into account the potential for non-response bias, which is, those that did not respond to the survey may have different WTP than respondents. Some people for example, are strongly opposed to the use of aerial poison baiting for pest control, regardless of whether used by DOC and TBfreeNZ (Green and Rohan, 2012), so could conceivably have a negative WTP. However, continued wide public support for the method suggests that this group is a small minority. To derive a credible lower limit, we assumed the mean WTP for non-respondents was zero, we consider that is highly conservative, given the broad support for conservation identified by other surveys (DOC, 2015). With that assumption national WTP for conservation benefits from TB-possum control is estimated at approx. $66m annually (in 2013 $NZ) and are therefore still greater than what is currently spent on obtaining them. That is consistent with evidence that the great majority of New Zealanders see possums as major threats to conservation and industry and that they should, ideally, be eradicated (Russell, 2014).

3.3. Policy implications and uptake

The results generated here were subsequently employed directly in CBA of OSPRI TB control activities (OSPRI, 2016). The ability to widen the scope of possible benefits demonstrated the gain to

[1] Two control methods x four biodiversity attributes x 25 forest classes = 200 areas in total.

managers in valuing programme outcomes not typically considered, nor able to be measured using conventional market-based economic method. These results underpinned a case for continued government support (on behalf of the public) of the TBfree management programme in NZ. Until now the NPMP for TB has focussed on reducing the threat to agricultural industries, having successfully achieved that to the extent that TB-related production losses and threats to NZ's ability to trade are minimal (Livingstone et al., 2015). Local and central government have contributed to the cost of the NPMP largely on a 'good neighbour' or 'exacerbator' basis because public and non-agricultural lands harboured TB-infected wildlife that undermine effort to reduce the disease on agricultural lands. However, the success of the NPMP has undermined the case for continued government support for what has reduced to a now modest benefit to agriculture. As a consequence, both the last two reviews of the NPMP in 2008-09 and 2014-15 canvassed the option of abandoning the NPMP (as a nationally coordinated and funded plan) in favour of locally based TB-possum control programmes funded by the direct agricultural beneficiaries. Such programmes would focus primarily on agricultural lands and only extend modest distances into the large tracts of native forest that comprise the bulk of such ecosystems.

The most recent review of the NPMP also canvassed national eradication of TB from wildlife as an option (PGG, 2015). That option required TB-possum control over 2-3m ha of native forest mostly remote from farmland not previously controlled i.e. at least as much again as the area depicted in Fig. 1. The benefit to agriculture from eliminating TB from those remote areas of native forest lies in enabling complete cessation of TB management everywhere. The direct and immediate benefit to agriculture of reduced TB risk to livestock would be minimal. In this context, our finding that the public are WTP substantial additional tax for the immediate benefits to conservation from TB-possum control in such areas therefore provided support for the national eradication option. Subsequently, government and industry agreed in 2016 not only to continue to fund the NPMP but also to adopt the objective of nationally eradicating the disease from livestock and wildlife by 2055, with government contributing approximately 40% of the annual cost of approximately $60-65m p.a. over the next 15 years, both as a 'good neighbour', and in return for biodiversity and environmental benefits (PGG, 2015).

Globally, there appear to be few, if any, similar studies aimed at valuing the incidental benefits of pest management actions, but there are parallel studies showing (for example) greater willingness to pay for forest carbon sequestration in Mexico where the co-benefits of that were higher (Torres et al., 2015). More broadly, however, this study adds to an increasing number of examples where choice experiments have been used to assess willingness to pay for the direct benefits of conservation or restoration activities through accurate depiction of a wide range of possible outcomes (Hjerpe and Hussain, 2016).

4. Conclusions

We conclude New Zealanders are willing to pay substantially more for additional conservation benefits over and above the amounts they are already paying for (by way of the tax revenue used to fund DOC pest control). Further, they appear willing to pay for those benefits even if they are derived incidentally from pest management conducted primarily for other purposes (in this case, the eradication of bovine tuberculosis from New Zealand). Further still, they appear to value protection of the forest as whole (through preservation of an intact forest canopy) than on lesser components of the ecosystem.

This study has demonstrated how non-market valuation methods based on choice experiments can be used to help inform high-level pest management decisions. By providing evidence that ancillary or co-benefits are seen by the public as worthwhile and important, our findings supported the case for governmental support for a pest management programme that otherwise might have been seen as solely being an industry problem. That enabled a more comprehensive assessment of all of the benefits (direct and ancillary) generated by TB management activities. By contributing significantly (we believe) to an overall analysis of costs and benefits, this study helped in achieving broad multi-party stakeholder commitment to a long-term multi-decade programme.

The specific outcome of this study is unlikely to be relevant to the management of TB in wildlife elsewhere in the world, because lethal control of wildlife hosts to low densities using poisoning are extremely unlikely to be acceptable in other developed countries where the disease has established in wildlife. Lethal control of TB-infected badgers (*Meles meles*) in Britain, for example, is highly controversial, and widely opposed. Outside the TB management context, however, we suggest that our approach of using experts to simply but meaningfully characterise conservation attributes provides a useful way of valuing complex abstract phenomena such as biodiversity and its conservation.

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