Economic Assessment of Good Neighbour Rules under the National Policy Direction for Pest Management 2015

Model definition and trial results

March 2017

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Executive Summary

This report describes a model that can be used to assess the ability of a Good Neighbour Rule (GNR) to meet the requirements of the National Policy Direction for Pest Management (NPD). The model has five worksheets:

- ***Key Assumptions*** –users select the pest species, discount rate, region, and various characteristics of the situation where boundary control is likely to be required. This worksheet also contains the buttons that run the model.
- ***Parameter Descriptions*** – summarises the purpose of each item in the Key Assumptions sheet, included for quick reference.
- ***Results*** – shows the results for both the Section 6 (costs and benefits) and Section 8 (reasonableness) tests under the NPD.
- ***Default Parameters*** – this contains the default parameters for each pest, and can be altered.
- ***Calculations*** – contains the background calculations for the model. It is not intended to be altered.

In order to use the model it is important to save the file as an alternate name, and to allow the use of Macros. If the model will not run when the "Calculate Results" button is clicked, it is most likely because you have not allowed Macros to operate in your worksheet.

The models provide a set of results for each pest, and a set of statements that describe how well the pest is likely to meet the tests of the NPD. The table and statements can be copied into the Section 71 report and edited as needed.

The trial model results generally indicate that the situations where GNRs can be justified tend to be limited to a small number of land uses and proneness classes. This conclusion is driven by the land uses on which the pest causes significant problems, the relativity of the control costs between source and receptor land uses, and the costs of inspection. Generally the larger the problem (i.e. the longer the boundary distance involved), the better the justification for a GNR.

1 Background

The Biosecurity Law Reform Bill was introduced to Parliament in November 2010 to update the Act. Part 5 of the Act 'Pest Management' received a number of amendments. These amendments led to the writing of the National Policy Direction for Pest Management 2015 (NPD) to better guide the development of what are now known as Regional Pest Management Plans (RPMPs). In addition to the assessment of benefits and costs in Section 6 of the NPD, Section 8 sets out a number of criteria that must be met, including the reasonableness of the costs imposed relative to those that would be incurred by the adjacent landholder, and the biological characteristics of the pest.

Section 6 of the NPD outlines the requirements for an analysis of the benefits and costs, and Section 8 gives direction for the construction of Good Neighbour Rules (GNRs).

Good neighbour rules can be applied to any species in a RPMP where a pest would spread to nearby land and cause unreasonable costs to that occupier. The rule is a directive to manage the spread of the pest to the adjacent and nearby land and the cost of rule compliance must be relative to the impact of the pest if the rule was not in place. The nearby occupier must be making an attempt to control the pest species.

Where the GNR is the only element of a strategy, a robust analysis of benefits and costs is required to ensure that GNRs meet the NPD criteria. Where the GNR is part of a wider objective with other rules and policies, the costs and benefits of the wider objective can be relied upon, but the requirements of Section 8 for reasonableness must still be met.

A collective project between Regional Councils is underway to help align the structure and rules of the various RPMPs. As part of the collective project, nine species have been identified as inter-regional pests to which GNRs may be applied: feral rabbits, possums, gorse, African feather grass, ragwort, nodding thistle, Scotch broom, nassella tussock and wilding conifers[1].

This report describes two user models (one for pest plants and one for pest animals) for undertaking GNR cost-benefit analyses, and provides a case study for each of the nine inter-regional pests.

2 Method

The situations in which GNRs may be applied have a number of characteristics. These include:

- The degree of separation (boundary clearance width) required in order to prevent the spread of the pest onto a neighbouring property.
- The density of pests on the infested (source) and controlled (receptor) sides of the boundary.
- The cost of control for heavily-infested and lightly-infested land.

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[1] 'Wilding conifers' potentially covers more than one pest species. This will need to be discussed with the client and an acceptable approach determined during project development.

- The land use on either side of the boundary.
- The length of boundary affected.
- The biological characteristics of the pest, including the rate at which it spreads and the longevity of any seed bank.
- The cost of inspection and intervention by the council in order to ensure that control is undertaken (i.e. compliance cost).

It is unlikely that a GNR will meet the criteria in Sections 6 and 8 in all circumstances, and the regional councils in a meeting on 25 May 2016 indicated that they wish to have a model that they can use to identify the situations where GNRs are appropriate. The model is intended to be used to develop the GNRs, and potentially also to assist the assessment of those situations where the GNR should be applied following complaint.

This report outlines the model methodology for undertaking the assessment of benefits, costs and Section 8 requirements. This enables individual councils to develop the GNRs for their situation.

1.1 Model structure

The model and underlying data are stored in MS Excel, with Visual Basic macros used to undertake the calculations in the background.

For the cost benefit (NPD Section 6) analysis the model is focused on identifying the situations where the GNR will produce a net benefit rather than requiring description of all possible parameters that would contribute to the cost and benefits. One of the critical variables is the relationship between the cost of inspection and the length of boundary where the pest is causing a nuisance. Where only a short boundary is involved, the cost of the council undertaking an inspection and requiring control will mean that, unless the pest is causing a significant issue, the costs will outweigh the benefits overall. However, where the length of boundary exceeds a certain threshold, the cost of inspection is more likely to be worthwhile (see Table 1 in Section 1.4 below). Therefore the model estimates the distance of boundary where the benefits will outweigh the costs, including the costs of inspection. This 'threshold' boundary distance is presented for a range of different land uses in both the property where the pest is originating (***source land use***) and where it is causing a nuisance (***receptor land use***).

For the reasonableness assessment (NPD Section 8) the model compares the costs of control for the source and receptor land uses, and reports a ratio between the two. The model does not provide an indication of whether this ratio is reasonable, but leaves it to the council to assess.

1.2 Opening the workbook

The workbooks are named ***Plant GNR model Final*** and ***Animal GNR model Final*** as supplied. It is suggested that the model you intend to work with is saved as a different name, allowing you to revert to the original in case you inadvertently overwrite some important data or workings.

When opened it is important to ***Enable Macros***. This may require you to obtain permissions from the administrator of your workplace – check this if there is not option available to enable macros, and the model is not working for you.

There are five worksheets in the model:

1. **Key Assumptions** – the main page for user selection of region, pest, and other key inputs that determine the scope of analysis for a pest in a region. The model is run from this page following selection of input parameters.
2. **Parameter Descriptions** – summarises the purpose of each item in the Key Assumptions sheet, included for quick reference.
3. **Results** – this presents the results of the analyses, both in terms of the cost- benefit analysis (NPD Section 6) and the reasonableness of the costs imposed under the GNR (NPD Section 8).
4. **Default Parameters** – contains the base input data for the modelling of a pest. The data is able to be altered by the user, but care should be taken not to overwrite important data.
5. **Calculations** – contains the underlying calculations for the modelling. This should not be altered by the user.

A more detailed description of each worksheet is provided below.

1.3 Key Assumptions Worksheet

There are a range of user inputs in this worksheet in both the plants and animals models, together with the button that runs the model. Each of the user inputs is described below.

- ***Discount rate*** – the default discount rate is set to 6%, which is the current NZ Treasury guidance for cost-benefit analyses[2]. However, there is no hard and fast rule in setting discount rates, and if you are not familiar with the use of discount rates it would be best to either use this rate, or check with your organisation if there is a standard discount rate you should use.

- ***Region and Pest*** – click on the dialog boxes to select the appropriate region and pest.

- ***Benefits, inspection costs, and whether the pest causes a problem:*** – default values are provided as uniform inputs for all pests. Productive enterprises have been estimated from Beef and Lamb NZ, DairyNZ, and proprietary models. No values are provided for non-productive land uses or for other ecosystem services on productive land uses, but your organisation may have values it uses for these situations. The default values can be altered if the impact of the pest is different from that shown, or if the value does not adequately reflect your region. Note that the default values assume 100% displacement of the productive value, so if the expected displacement is less than this the benefit should be reduced accordingly. Add any alternate values or ecosystem services values onto productive values and enter them in this table. This table also includes a TRUE/FALSE matrix to indicate whether the pest causes a problem on a particular land use type – this accounts for the fact that for some land uses certain pests tend not to be invasive because of the land management practices or

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[2] **http://www.treasury.govt.nz/publications/guidance/planning/costbenefitanalysis/currentdiscountrates**

characteristics of the habitat. The default values can be restored by clicking the ***Restore Default Values*** button.

- ***ANIMAL MODEL ONLY: Cost of control by proneness class***: this set of parameters is in the same table as the benefits, inspection costs etc. described above. It provides for easy user alteration of the cost of a control operation on different proneness types depending on whether there is immigration or not. The assumption is that the boundary control will prevent immigration, allowing for longer control intervals and/and or lower costs for the receptor land use.

- ***PLANT MODEL ONLY: Cost of control by land use***: this set of parameters is in the same table as the benefits, inspection costs etc. described above. It provides for easy user alteration of the cost of a control operation on different land uses, for both dense and scattered infestations. The default values are for costs to be uniform across land uses.

- ***PLANT MODEL ONLY: Current abundance of the pest*** – two options are provided depending on whether the pest is locally common or rare. This parameter affects the spread distance for the pest and the time it takes to achieve maximum density. Where the pest is widespread a shorter spread distance and a faster time to maximum density is used.

- ***PLANT MODEL ONLY: Density of the pest*** –two options are provided depending on whether the source infestation consists of dense or scattered plants. This affects both the cost of control for the source land use, but also the extent of any benefit the source land use may receive from control – there is greater benefit to the source land use from controlling a dense infestation than a scattered infestation. Just below this box is a set of cells that provide for user input of control costs. Ongoing control costs for source and receptor are based on scattered infestations, and initial control costs for the source land will depend on whether it is a scattered or dense infestation.

- ***PLANT MODEL ONLY: Seed bank threshold*** – this dialog box determines whether the contribution of a soil seed bank to the pest plant occurrence on the receptor land is to be considered in the model. If a seed bank is to be considered, the model assumes that the weed's occurrence on the receptor land is due to the seed bank until such time as only 20% of the seeds in the bank remain. The receptor landholder (rather than the source landholder) will need to continue control until this 20% point is reached. The figure of 20% is used as default but can be altered by changing cell P30 in the **Default Parameters** worksheet.

- ***Inspection frequency*** – this dialog box allows the user to select how often the inspection has to be repeated, ranging from once only to every five years. It affects the annual average cost of inspection in the calculation of costs and benefits.

- ***Calculate Results*** – this button implements the calculation of the range of values for all possible combinations of the defined source and receptor land uses. The model window will become unresponsive for a period up to 60 seconds, then the window will move to the ***Results*** worksheet.

- ***Boundary clearance width*** – the distance back from the boundary that is required to be cleared in order to prevent dispersal onto the neighbouring property. This figure is used to calculate spread and clearance areas. The default value for plants is set at the distance which satisfies the combination of preventing 90% (or user set) of propagules from falling on a neighbour, and also that 90% of the propagules are from the neighbour and not from an alternative source. The default 90% figures for plant pests can be changed in cells P32 and P33 in the **Default Parameters** worksheet. Users can also over-ride the default boundary clearance figure for the pest plants to reflect local conditions.

The default value provided for animal pests is based on current practice, and can be user-altered. For animal pests a boundary clearance width of 500m for rabbits is included, based on ECan experience. For possums a distance of 2000m has been included, but this has no specific justification and should be altered with better information from local conditions.

1.4 Results Worksheet

The results worksheet provides two sets of tables and two sets of statements. One set of tables and statements relates to the Section 6 (cost-benefit) requirements, and the other set relates to the Section 8 (reasonableness) requirements.

1.4.1 Section 6 requirements

The table for Section 6 requirements is on the left side of the **Results** worksheet in blue. For all situations where there was a positive net benefit from requiring the source land use to control the pest, a value is shown in the relevant combination of source and receptor land uses. The value in the cell shows the *minimum length of boundary* (in km) over which the pest would need to be causing a problem in order for the benefits to outweigh the costs. Where no cost is likely to be incurred by the receptor landholder, the cell is left blank. Where the costs always exceed the benefits regardless of the boundary length involved, a “C > B” is recorded in the cell. The colour of the cell indicates whether the benefits are likely (green), possibly or probably (orange), or do not or are unlikely (red) to outweigh the costs.

The associated set of statements for Section 6 gives the situations where the benefits (1) either do not or are very unlikely to exceed the costs, (2) are very likely to exceed the costs, or (3) may possibly or probably exceed the costs. The distances used to describe these thresholds are shown in Table 1 below. These values can be altered in the **Default Parameters** worksheet in cells S95:S99.

Table 1: Threshold boundary distance values for various likelihoods of the benefits exceeding costs.

Likelihood of benefits exceeding costs	**Distance of infestation required (m)**
No benefit (red)	0
Definitely benefit (green)	100
Probably a benefit (orange)	500
Possibly a benefit (orange)	1000
Unlikely to be benefit (red)	2000

1.4.2 Section 8 requirements

The results of the Section 8 analysis are shown on the right side of the ***Results*** worksheet in green. The values in the cells show only those situations where the pest is likely to cause a problem for receptor land uses. The figure in the cell is the ratio between the costs for the source and receptor land uses. The higher the ratio the less reasonable the costs are for the source land use, and therefore the more difficult it is to satisfy the requirements of Section 8. The colour of the cell indicates whether for that combination the costs are likely (green), possibly or probably (orange), or are unlikely (red) to be considered reasonable the costs.

The statements below the table puts the model results into a format to help meet the requirements of Section 8. The first of these uses the information in the **Key Assumptions** page to identify the situations where the receptor landholder would incur costs as a result of inaction by the neighbour (Section 8(1)(a)). The second statement uses the range of ratios in the table above to provide support for Section 8(1)(e)(ii) regarding the reasonableness of the costs for the source landholder relative to the costs for the receptor landholder. This second statement may require some editing if there is no difference between the highest and lowest ratio of costs. The thresholds for the reasonableness tests are shown below in Table 2 and can be changed in cells X95:X96 in the ***Default Parameters*** worksheet.

Table 2: Thresholds for definition of reasonableness for ratio between costs for source landholder and costs otherwise incurred by the receptor landholder

Threshold value for reasonableness	Source cost/Receptor cost
Reasonable (green)	1.2
Moderate (orange)	1.5
Unreasonable (red)	>1.5

1.5 Default Parameters Worksheet

The **Default Parameters** worksheet contains the bulk of the input data for the modelling. It is intended to be altered by knowledgeable people only. The datasets are briefly described below, and more details on the data sources are provided in the appendices.

Cost of control – The per hectare cost of control is given in the yellow coloured set of cells (see Appendix A for further details). For pest plants this varies according to whether the pest is present as a scattered or dense infestation. For the pest animals this varies according to the 'proneness' of the land use or land type to the pest, and whether the land is subject to 'spillover' i.e. immigration of individuals from neighbouring properties. The definitions of the proneness classes are shown on the right of these tables in columns V to Z.

There is also a set of assumptions shown in green in this part of the worksheet, which relates to whether the pest is a problem on a particular land use. Where a pest is not a problem, there are typically no control costs or benefits expected from control. TRUE is used to indicate that the pest is a problem on that particular land use, and FALSE to indicate that it is not a proble. These can be altered either here or in the Key Assumptions sheet on a case by case basis.

Biological Characteristics – Spread distance – this is shown in blue on the worksheet. It provides information on the spread distance for a pest in an area, which is equivalent to the boundary control distance and for plant pests varies according to whether the pest is widespread in an area or region, or if it is only of limited distribution. The spread figures are discussed further in Appendix B.

PLANT MODEL ONLY: Biological Characteristics – Population growth rates – This part of the worksheet also provides information on population growth rates for plant pests. The population growth rates are a based on the time taken for the pest to go from clear ground to displacing 90% of the relevant value for a land use type (see Appendix B2) – this allows the calculations to take into account any losses in production or other values that may occur on the source property if the pest is not controlled.

PLANT MODEL ONLY: Biological characteristics - Seed Bank – the input parameters for the seed bank calculations are shown in brown. These are needed because where there is a seed bank in the soil it is likely that control will be required in the receptor area regardless of whether the neighbouring property is contributing propagules, and the relative difference in costs with and without a GNR will be too small to be worth calculating. The basis of the seed bank calculations is discussed further in Appendix D.

There is an additional set of inputs to the right of the main Biological characteristics data, in light brown. This contains:

- *Threshold for seedbank remaining* – an estimate of the proportion of the seedbank remaining before it is no longer considered the primary source of weed seeds on a property.
- *Years since land was clear* – allows for the receptor land to have been clear for a number of years prior to their complaint. Default is set to 0, which assumes that the land was cleared at the same time the complaint was made.
- *Proportion of propagules* –the proportion of propagules that is considered reasonable to prevent dispersal to a neighbour. A lower proportion results in a shorter spread distance.
- *Proportion from neighbour* –the threshold for the proportion of pest propagules on the receptor land deemed to have arrived from the adjacent neighbour (source). A higher proportion results in a shorter spread distance, since further away there is greater chance that the seed will have arrived from somewhere else.

Benefits – these are shown in red in the worksheet, and provide estimates of the productive losses that will occur if the pest is not controlled on the source land. The definitions of the land uses are shown in Table 3 below. The benefit estimates are based on the last five years of data from Beef and Lamb NZ and DairyNZ Economic Survey[3] information, and proprietary information (horticulture)[4]. Benefit estimates for rabbits are derived from ECan (Harris, 2016). Possum control benefits are based on consuming pasture and displacing production, estimated from Greer (2006) using 0.68 possums/ha for moderate prone and 3 possums ha (Cowan, 2009) for extreme prone[5]. Note that the model will assume full displacement of the values – if less than 100% displacement will occur on the source property, the benefit values should be adjusted downward.

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[3] For some years not all regional information was available.

[4] Based on central NZ horticulture and vegetable production systems. Horticulture is used for Nelson, Tasman, Marlborough, Manawatu-Wanganui, Wellington and Bay of Plenty. The vegetable production system is used for other regions.

[5] $0/ha for low prone and linear interpolation between moderate and extreme prone for high prone.

For some land uses it may be appropriate to include ecosystem services values associated with recreation, biodiversity, flood protection etc. These should be added to the benefits either in the **Default Parameters** worksheet or as a one-off for an individual pest in the **Key Assumptions** worksheet.

Table 3: Definitions of land uses in model

Land use	**Definition**
Dairy	Dairy operation, raising of replacements dependent on region. Sourced from DairyNZ.
Sheep and beef Intensive	Easy contour or flat farmland with the potential for high production. Mostly carrying between six and 15 stock units per hectare.
Arable	Located mainly on the Canterbury Plains. A high proportion of revenue is derived from grain and small seed production as well as stock finishing.
Horticulture	Includes permanent (orchard, viticulture, tree crop) as well as annual vegetable production.
Hill country	Ranging from harder hill country in the North Island carrying 6 – 10su/ha, easier North Island hill country carrying 7 – 13 su/ha, and South Island hill country carrying 2 – 7 su/ha.
High country	Located mainly in the higher altitude areas of the South Island, extensive land carrying mainly fine wool.
Conservation	Land managed for conservation purposes.
Forestry	Production forestry.
Non Productive	Includes urban, waste, transport corridors, , and land not otherwise managed for conservation or productive purposes.

Inspection costs – these are shown in grey on the worksheet, and are based on information provided by regional councils or as estimates where no information is available. They can be relatively simply updated within this worksheet, or altered in the ***Key Assumptions*** worksheet.

1.6 Calculations Worksheet

The calculations worksheet is not intended to be altered by the user. This section is provided for information purposes only.

- The *Primary assumptions* part of the worksheet collects the input data from other parts of the workbook.
- The *Variable inputs* part of the worksheet provides for those variables that are altered by the macro code to produce the matrix of results.
- The *Cashflow* part of the worksheet contains the main calculations of Net Present Value (NPV). These are divided into two scenarios: (1) without intervention - where

the receptor landholder incurs the costs, and (2) with intervention – where the source land use bears the costs but also potentially receives some benefit (if the pest is a problem on that particular land use).

- The *Results* part of the worksheet collates the unfiltered results and allows for the development of statements about the impacts of the GNR.

2 Operating the Model

1. Open the model and ***Save As*** using an alternate name.
2. Open the ***Key Assumptions*** worksheet.
3. You may need to resize the worksheet to fit appropriately on the screen.
4. Check the ***Discount Rate*** is appropriate for that which is normally used in your region. This may vary according to the type of pest involved (conservation, production etc).
5. Select ***Region***
6. Select ***Pest.***
7. Check ***Benefits*** are appropriate for the pest under each land use land use and update as necessary. If you wish to include other ecosystem services values, they should be added to the production values and input into the table under the appropriate land uses.
8. Check the ***Inspection Costs*** are appropriate for the pest and land use and update as necessary.
9. Make any alterations to the control costs and whether the pest causes a problem for each land use/proneness class.
10. Click on the appropriate choice regarding the ***Current Distribution*** of the pest, the ***Density of The Source Infestation***, the ***Seed Bank*** and the requirement for ***Repeat inspection***.
11. Check the ***Boundary clearance width*** and alter as necessary (plants) or in the case of animals enter an appropriate distance for your region. This figure is in m.
12. Click the ***Calculate Results*** button.
13. Check the results in the two tables.
14. Copy the result statements below the tables into the relevant NPD Section 6 and Section 8 justification, checking that any editing is done to adjust the generic nature of the statements to the actual results.
15. There is a **<u>Summary of Assumptions</u>** below the main results in rows 29 – 40. These can be copied into the Section 71 report to explain the assumptions used.
16. Return to the ***Key Assumptions*** page to test alternate assumptions.

3 Results

A series of trial runs were made for each pest, with the region varying by pest. These are shown in the following sections, but should not be used for a RPMP as they have not been verified for the regions specified.

3.1 Gorse

3.1.1 Key Assumptions

Region	Northland								
Pest	Gorse								
Discount rate	$0								
Abundance	Pest locally common								
Density of source	Source infestation is scattered plants								
Seed bank included	Yes								
Boundary clearance width (m)	39								
Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$2,154	$564	$1,581	$9,100	$564	$57	$0	$0	$0
Cost of inspection and enforcement	$100	$100	$100	$100	$200	$400	$200	$200	$100
Pest is a problem on this land use	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	TRUE	FALSE

3.1.2 Section 6

Gorse NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is scattered plants

Receptor Land use

	Dairy	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Dairy	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥
Sheep and beef Intensive	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥
Arable	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥
Horticulture	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥
Hill country	🟥	🟥	🟥	🟥	130	130	🟥	130	🟨
High country	🟥	🟥	🟥	🟥	>2000m	>2000m	🟥	>2000m	🟥
Conservation	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥
Forestry	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥
Non Productive	🟥	🟥	🟥	🟥	C > B	C > B	🟥	C > B	🟥

Cost Benefit Analysis statements (NPD Section 6)

When the Source infestation is scattered plants the benefits of the Good Neighbour Rule for Gorse are not likely to outweigh the costs when the source land use is in Dairy, Sheep and beef Intensive, Arable, Horticulture, High country, Conservation, Forestry, Non Productive, nor when the party being affected is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Conservation, Non Productive.

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Gorse are very likely to outweigh the costs in no situations.

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Gorse may possibly or probably outweigh the costs when the party being affected is in Hill country, High country, Forestry.

3.1.3 Section 8

Gorse NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving landholder - Source infestation is scattered plants

Receptor Landuse

Source Landuse

	Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Dairy	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Sheep and beef Intensive	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Arable	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Horticulture	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Hill country	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
High country	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Conservation	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Forestry	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs
Non Productive	No costs	No costs	No costs	No costs	1.00	1.00	No costs	1.00	No costs

3.2 Ragwort

3.2.1 Key Assumptions

Region	Auckland								
Pest	Ragwort								
Discount rate	$0								
Abundance	Pest locally common								
Density of source	Source infestation is scattered plants								
Seed bank included	Yes								
Boundary clearance width (m)	60								
Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$2,154	$564	$1,581	$9,100	$564	$57	$0	$0	$0
Cost of inspection and enforcement	$225	$225	$225	$225	$225	$225	$225	$225	$225
Pest is a problem on this land use	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE

3.2.2 Section 6

Ragwort NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is scattered plants

Receptor Land use

Source Land use		Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
	Dairy	20								
	Sheep and beef Intensive	C > B								
	Arable	C > B								
	Horticulture	C > B								
	Hill country	C > B								
	High country	C > B								
	Conservation	C > B								
	Forestry	C > B								
	Non Productive	C > B								

Cost Benefit Analysis statements (NPD Section 6)

When the Source infestation is scattered plants the benefits of the Good Neighbour Rule for Ragwort are not likely to outweigh the costs when the source land use is in Sheep and beef Intensive, Arable, Horticulture, Hill country, High country, Conservation, Forestry, Non Productive, nor when the party being affected is in Sheep and beef Intensive, Arable, Horticulture, Hill country, High country, Conservation, Forestry, Non Productive.

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Ragwort are very likely to outweigh the costs when the party being affected is in Dairy.

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Ragwort may possibly or probably outweigh the costs in no situations.

3.2.3 Section 8

Ragwort NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving Landholder - Source infestation is scattered plants

		Receptor Land use								
		Dairy	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Source Land use	**Dairy**	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Sheep and beef Intensive	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Arable	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Horticulture	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Hill country	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	High country	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Conservation	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Forestry	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs
	Non Productive	1.00	No costs	No costs	No costs	No costs	No costs	No costs	No costs	No costs

Reasonableness of the costs imposed (NPD Section 8e(ii))

When the Source infestation is scattered plants the cost of compliance with the rule for the source landholder is between the same as the cost for the occupier who would otherwise be affected. The test of reasonableness for Section 8 is therefore likely to be met.

3.3 African Feather grass

3.3.1 Key Assumptions

Region	Bay of Plenty								
Pest	African feather grass								
Discount rate	6%								
Abundance	Pest locally rare								
Density of source	Source infestation is scattered plants								
Seed bank included	No								
Boundary clearance width (m)	191								
Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$3,549	$564	$1,581	$13,700	$564	$57	$0	$0	$0
Cost of inspection and enforcement	$100	$100	$100	$100	$200	$400	$100	$100	$100
Pest is a problem on this land use	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE

3.3.2 Section 6

African feather grass NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is scattered plants

Receptor Land use

Source Land use	Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Dairy	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥
Sheep and beef Intensive	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥
Arable	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥
Horticulture	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥
Hill country	🟥	🟥	🟥	🟥	20	20	🟥	🟥	🟩
High country	🟥	🟥	🟥	🟥	600	600	🟥	🟥	🟨
Conservation	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥
Forestry	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥
Non Productive	🟥	🟥	🟥	🟥	C > B	C > B	🟥	🟥	🟥

Cost Benefit Analysis statements (NPD Section 6)

When the Source infestation is scattered plants the benefits of the Good Neighbour Rule for African feather grass are not likely to outweigh the costs when the source land use is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Conservation, Forestry, Non Productive, nor when the party being affected is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Conservation, Forestry, Non Productive,

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for African feather grass are very likely to outweigh the costs when the party being affected is in Hill country, High country,

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for African feather grass may possibly or probably outweigh the costs in no situations.

3.3.3 Section 8

African feather grass NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving Landholder - Source infestation is scattered plants

		Receptor Land use								
		Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Source Land use	**Dairy**	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Sheep and beef Intensive	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Arable	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Horticulture	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Hill country	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	High country	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Conservation	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Forestry	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00
	Non Productive	No costs	No costs	No costs	No costs	1.00	1.00	No costs	No costs	1.00

Reasonableness of the costs imposed (NPD Section 8e(ii))

When the Source infestation is scattered plants the cost of compliance with the rule for the source landholder is the same cost for the occupier who would otherwise be affected. Therefore the GNR is likely to meet the tests of Section 8.

3.4 Nodding Thistle

3.4.1 Key Assumptions

Region	Hawkes Bay								
Pest	Nodding thistle								
Discount rate	6%								
Abundance	Pest locally common								
Density of source	Source infestation is scattered plants								
Seed bank included	No								
Boundary clearance width (m)	39								
Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$3,241	$564	$1,581	$13,700	$407	$57	$0	$0	$0
Cost of inspection and enforcement	$100	$100	$100	$100	$200	$400	$200	$200	$100
Pest is a problem on this land use	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	FALSE	FALSE	FALSE

3.4.2 Section 6

Nodding thistle NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is scattered plants

Receptor Land use

		Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Source Land use	**Dairy**	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Sheep and beef Intensive	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Arable	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Horticulture	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Hill country	>2 km	>2 km	>2 km	>2 km	0.17	0.17	>2 km	>2 km	0.17
	High country	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Conservation	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Forestry	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km
	Non Productive	>2 km	>2 km	>2 km	>2 km	>2km	>2km	>2 km	>2 km	>2km

Cost Benefit Analysis statements (NPD Section 6)

When the Source infestation is scattered plants the benefits of the Good Neighbour Rule for African feather grass are not likely to outweigh the costs when the source land use is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Conservation, Forestry, Non Productive, nor when the party being affected is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Conservation, Forestry, Non Productive.
When the Source infestation is scattered plants the benefits of the Good Neighbour rule for African feather grass are very likely to outweigh the costs when the party being affected is in Hill country, High country,
When the Source infestation is scattered plants the benefits of the Good Neighbour rule for African feather grass may possibly or probably outweigh the costs in no situations.

3.5 Broom

3.5.1 Assumptions

Region	Taranaki								
Pest	Broom								
Discount rate	6%								
Abundance	Pest locally common								
Density of source	Source infestation is scattered plants								
Seed bank included	No								
Boundary clearance width (m)	39								
Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$3,430	$564	$1,581	$9,100	$564	$57	$0	$0	$0
Cost of inspection and enforcement	$330	$440	$220	$220	$440	$440	$37	$37	$37
Pest is a problem on this land use	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	TRUE	FALSE

3.5.2 Section 6

Broom NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is scattered plants

Receptor Land use

Source Land use	Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Dairy					C > B	C > B	C > B	C > B	
Sheep and beef Intensive					C > B	C > B	C > B	C > B	
Arable					C > B	C > B	C > B	C > B	
Horticulture					C > B	C > B	C > B	C > B	
Hill country					270	270	270	270	
High country					>2000m	>2000m	>2000m	>2000m	
Conservation					C > B	C > B	C > B	C > B	
Forestry					C > B	C > B	C > B	C > B	
Non Productive					C > B	C > B	C > B	C > B	

Cost Benefit Analysis statements (NPD Section 6)

When the Source infestation is scattered plants the benefits of the Good Neighbour Rule for Broom are not likely to outweigh the costs when the source land Sheep and beef Intensive, Arable, Horticulture, High country, Conservation, Forestry, Non Productive, nor when the party being affected is in Dairy, Sheep an Arable, Horticulture, Non Productive,

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Broom are very likely to outweigh the costs in no situations.

When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Broom may possibly or probably outweigh the costs when the par is in Hill country, High country, Conservation, Forestry,

3.5.3 Section 8

Broom NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving Landholder - Source infestation is scattered plants

Receptor Land use

Source Land use	Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Dairy	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Sheep and beef Intensive	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Arable	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Horticulture	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Hill country	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
High country	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Conservation	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Forestry	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs
Non Productive	No costs	No costs	No costs	No costs	1.00	1.00	1.00	1.00	No costs

Reasonableness of the costs imposed (NPD Section 8e(ii))

When the Source infestation is scattered plants the cost of compliance with the rule for the source landholder is between 1 and 1 times the cost for the occupier who would otherwise be affected

3.6 Nassella tussock

3.6.1 Key Assumptions

Region	Marlborough
Pest	Nassella tussock
Discount rate	6%
Abundance	Pest locally common
Density of source	Source infestation is scattered plants
Seed bank included	No
Boundary clearance width (m)	60

Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$4,489	$564	$1,581	$13,700	$221	$57	$0	$0	$0
Cost of inspection and enforcement	$100	$600	$600	$600	$800	$800	$800	$200	$150
Pest is a problem on this land use	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE

3.6.2 Section 6

Nassella tussock NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is scattered plants

Receptor Land use

		Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Source Land use	**Dairy**	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥
	Sheep and beef Intensive	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥
	Arable	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥
	Horticulture	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥
	Hill country	🟥	🟥	🟥	🟥	700	700	700	🟥	🟥
	High country	🟥	🟥	🟥	🟥	>2000m	>2000m	>2000m	🟥	🟥
	Conservation	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥
	Forestry	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥
	Non Productive	🟥	🟥	🟥	🟥	C > B	C > B	C > B	🟥	🟥

Cost Benefit Analysis statements (NPD Section 6)
When the Source infestation is scattered plants the benefits of the Good Neighbour Rule for Nassella tussock are not likely to outweigh the costs when the source land use is in Dairy, Sheep and beef Intensive, Arable, Horticulture, High country, Conservation, Forestry, Non Productive, nor when the party being affected is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Forestry, Non Productive.
When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Nassella tussock are very likely to outweigh the costs in no situations.
When the Source infestation is scattered plants the benefits of the Good Neighbour rule for Nassella tussock may possibly or probably outweigh the costs when the party being affected is in Hill country, High country, Conservation.

3.6.3 Section 8

Nassella tussock NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving Landholder - Source infestation is scattered plants

Receptor Land use

Source Land use

	Dairy	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Dairy	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Sheep and beef Intensive	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Arable	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Horticulture	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Hill country	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
High country	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Conservation	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Forestry	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs
Non Productive	No costs	No costs	No costs	No costs	1.00	1.00	1.00	No costs	No costs

Reasonableness of the costs imposed (NPD Section 8e(ii))

When the Source infestation is scattered plants the cost of compliance with the rule for the source landholder is between the same as the cost for the occupier who would otherwise be affected. The GNR is therefore likely to meet the test of reasonableness under Section 8.

3.7 *Pinus contorta* (lodgepole pine)

3.7.1 Key Assumptions

Region	Marlborough
Pest	Lodgepole or contorta pine
Discount rate	6%
Abundance	Pest locally rare
Density of source	Source infestation is dense
Seed bank included	No
Boundary clearance width (m)	191

Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Benefits from controlling pest ($/ha/annum)	$4,489	$564	$1,581	$13,700	$221	$57	$0	$0	$0
Cost of inspection and enforcement	$100	$600	$600	$600	$800	$800	$800	$200	$150
Pest is a problem on this land use	FALSE	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE	FALSE	FALSE

3.7.2 Section 6

Lodgepole or contorta pine NPD Section 6 - Length of boundary in km required for there to be a net benefit - Source infestation is dense

Receptor Land use

		Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country	Conservation	Forestry	Non Productive
Source Land use	**Dairy**					C > B	C > B	C > B		
	Sheep and beef Intensive					C > B	C > B	C > B		
	Arable					C > B	C > B	C > B		
	Horticulture					C > B	C > B	C > B		
	Hill country					470	470	470		
	High country					C > B	C > B	C > B		
	Conservation					C > B	C > B	C > B		
	Forestry					C > B	C > B	C > B		
	Non Productive					C > B	C > B	C > B		

Cost Benefit Analysis statements (NPD Section 6)
When the Source infestation is dense the benefits of the Good Neighbour Rule for Lodgepole or contorta pine are not likely to outweigh the costs when the source land use is in Dairy, Sheep and beef Intensive, Arable, Horticulture, High country, Conservation, Forestry, Non Productive, nor when the party being affected is in Dairy, Sheep and beef Intensive, Arable, Horticulture, Forestry, Non Productive.
When the Source infestation is dense the benefits of the Good Neighbour rule for Lodgepole or contorta pine are very likely to outweigh the costs in no situations.
When the Source infestation is dense the benefits of the Good Neighbour rule for Lodgepole or contorta pine may possibly or probably outweigh the costs when the party being affected is in Hill country, High country, Conservation.

3.7.3 Section 8

Lodgepole or contorta pine NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving Landholder - Source infestation is dense

Receptor Land use

Source Land use	**Dairy**	**Sheep and beef Intensive**	**Arable**	**Horticulture**	**Hill country**	**High country**	**Conservation**	**Forestry**	**Non Productive**
Dairy	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Sheep and beef Intensive	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Arable	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Horticulture	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Hill country	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
High country	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Conservation	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Forestry	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89
Non Productive	No costs	No costs	No costs	No costs	8.89	8.89	8.89	No costs	8.89

Reasonableness of the costs imposed (NPD Section 8e(ii))

When the Source infestation is dense the cost of compliance with the rule for the source landholder is 9 times the cost for the occupier who would otherwise be affected. It is unlikely under the assumptions used here that the GNR rule can be considered reasonable under Section 8(e)(ii).

3.8 Feral Rabbits

3.8.1 Key Assumptions

Region	Otago			
Pest	Rabbits			
Discount rate	6%			
Boundary clearance width (m) (example only)	500			
Land use	**Low**	**Moderate**	**High**	**Extreme**
Benefits from controlling pest ($/ha/annum)	$0	$93	$56	$5
Cost of inspection and enforcement	$200	$200	$200	$200

3.8.2 Section 8

Feral Rabbits NPD Section 6 - Length of boundary in km required for there to be a net benefit

Receptor land use

Source land use	**Low**	**Moderate**	**High**	**Extreme**
Low	🟥	430	160	140
Moderate	🟥	60	50	40
High	🟥	470	170	140
Extreme	🟥	C > B	C > B	C > B

Cost Benefit Analysis statements (NPD Section 6)
The benefits of the Good Neighbour Rule for Feral rabbits are not likely to outweigh the costs when the source land use is in the Extreme Feral rabbits proneness class or when the party being affected is in the Low feral rabbits proneness class.
The benefits of the Good Neighbour rule for feral rabbits are very likely to outweigh the costs when the party being affected is in the Moderate, High, Extreme Feral rabbits proneness class.
The benefits of the Good Neighbour rule for feral rabbits may possibly or probably outweigh the costs in no situations.

3.8.3 Section 6

Feral rabbits NPD Section 8(e)(ii) - Ratio of costs for Source Landholder to the costs for the Receiving Landholder

Source land use		Receptor land use			
		Low	**Moderate**	**High**	**Extreme**
	Low	No costs	0.12	0.07	0.04
	Moderate	No costs	1.00	0.53	0.30
	High	No costs	1.89	1.00	0.57
	Extreme	No costs	3.29	1.75	1.00

Reasonableness of the costs imposed (NPD Section 8e(ii))

The cost of compliance with the rule for the source landholder is between 0.04 and 3.29 times the cost for the occupier who would otherwise be affected.

4 Bibliography

Cowan, P. (2009). *Measuring the benefits of possum control for pasture* . Palmerston North: Landcare Research Contract Report: LC0910/014 .

Greer, G. (2006). *The Economic Benefits of the Possum Control Area Programme.* Lincoln: AERU Research report No. 282. May 2006. https://researcharchive.lincoln.ac.nz/bitstream/handle/10182/154/aeru_rr_282.pdf?sequence=3&isAllowed=y.

Harris, S. (2016). Christchurch: LWP Ltd Draft report prepared for Environment Canterbury.

5 Appendices

Appendix A Cost of control

Pest Control Costs – for Good Neighbour Rule CBAs
Melissa Hutchison, Wildland Consultants
October 2016

GORSE

Annual control costs by landowners:
- ECan (2016) Low density to High density infestation **$100-1,000/ha**.
- Taranaki Regional Council (2015) **$170-$190/ha**.
- Hawkes Bay RC (2015) $500,000 over 50,000 ha = **$10/ha**.
- Auckland Council (2016) **$15-$12,000/ha**.

Periodic control costs
- ECan (2016) **$6.80/ha**.

SCOTCH BROOM

Annual control costs by landowners:
- ECan (2016) Low density to High density infestation **$100-1,000/ha**.
- Taranaki Regional Council (2015) **$120-$130/ha**.

RAGWORT

Annual control costs by landowners:
- Taranaki Regional Council (2015) **$120-$150/ha**.
- Hawkes Bay RC (2015) $50,000 over 100,000 ha = **$0.50/ha**.

NODDING THISTLE

Annual control costs by landowners:
- Taranaki Regional Council (2015) **$150-$160/ha**.
- Hawkes Bay RC (2015) $50,000 for Site-led over 1,383,200 ha = **$0.04/ha**.

AFRICAN FEATHER GRASS

Annual control costs by landowners
- Taranaki Regional Council (2015) **$150-$160/ha**.
- Bay of Plenty Regional Council (2003) **$60/ha**.

Annual control costs by Council

- Hawkes Bay RC (2015) $1100 for Sustained Control over 1 ha = **$1,100/ha**.

Periodic control costs

- ECan (2016) **$4.50/ha**.

NASSELLA TUSSOCK

Annual control costs by landowners

- ECan (2016) Low density to High density infestation **$10-45/ha**.
- Bay of Plenty Regional Council (2003) **$500/ha**.

Annual control costs by Council

- Hawkes Bay RC (2015) $14,780 for Progressive Containment over 50 ha = **$295.60/ha**.

Periodic control costs

- ECan (2016) **$4.50/ha**.

From Rural Delivery website:
http://www.ruraldelivery.net.nz/2005/10/nassella-tussock/
Nassella tussock is a perennial tussock native to South America, which can form a dense mat throughout pastures. It is unpalatable to sheep and cattle. It produces numerous seeds on feathery wind-dispersed panicles (branched clusters) and thrives in drought-prone grassland. Viable seeds are present on plants from early November, peaking in number around New Year.

Fortunately, seeds do not survive in the soil for ever – in some soils most are dead within five years. Also seeds do not continue ripening once a plant is grubbed out. Research has shown that population growth depends more on year-to-year seeding than on survival of seeds in the soil. This means that any control program designed to prevent all seeding will be the most effective in reducing re-infestation to low levels. The majority of new seedlings emerge in the autumn. The grubbing or spraying prior to flower panicle emergence in November prevents the production of viable seed.

From ECan 2012:
http://www.epa.govt.nz/search-databases/HSNO%20Application%20Register%20Documents/APP201170_SUBMISSION102547%20-%20Canterbury%20Regional%20Council%20-%2021MAR2012%20Additional%20Document%20(1).pdf

Nassella tussock (*Nassella trichotoma*) is similarly suited to the Chilean needle grass habitat. Despite a long history of control effort, it continues to be present on approximately 265,000 hectares of land in Canterbury. Much of this land is non-arable Class VI and VII.

Hand grubbing has been the predominant method of control in the absence of a suitable chemical herbicide. Using hand control tools (grubbing or even chemical application) on steep land is physically demanding and often plants are missed. Now that a selective herbicide (Taskforce) is available its aerial application represents a major opportunity to expand the effectiveness of control. For nassella tussock, the ability to substantially reduce the number of plants that mature sufficiently to produce seed has a considerable bearing on population levels. Aerial application has greater likelihood of all plants being destroyed prior to seed set.

The control management for nassella tussock involves land owners undertaking control programmes with property inspections by Environment Canterbury to ensure compliance. The cost of this strategy is $520,000 per annum for inspection and enforcement, and approximately $1.2 million annually for control. Hand grubbing is the major control tool. Costs on average 0.2 ha/hour, with an additional 10 seconds/plant for grubbing. Contract control costs average $20/hour (2002 rates).

While the cost of Taskforce herbicide and its aerial application is greater than an annual grubbing operation, the three to five year effectiveness of Taskforce makes its use more cost effective than annual grubbing. More importantly, it is the increased efficacy that Taskforce provides compared with hand grubbing.

From Marlborough DC website:
http://www.marlborough.govt.nz/Environment/Biosecurity/Declared-Pest-Species/Nassella-Tussock.aspx

How can it be controlled?
There are two main methods of controlling Nassella: Grubbing and spraying with Taskforce herbicide. To stop the wind from picking up the seedheads and spreading the plant further the control work needs to be done prior to October (ie; before it has the potential to seed). Grubbing has been the traditional control tool for many years. Care must be taken to grub out all the root system and not too much soil is left on the grubbed plant. Taskforce has been a relatively new addition to controlling Nassella and is able to effectively control Nassella over large areas (as well as spot spraying) and provide a residue in the soil to prolong the control effect.

From HBRC website:
http://www.hbrc.govt.nz/assets/Document-Library/Information-Sheets/Plant-Pests/PCPP7.pdf
Chemical control - Spraying with Dalapon or glyphosate is usually only done on densely infested areas.

From Kriticos et al. 2004:
In New Zealand, nassella tussock spread rapidly during the early 1900s to occupy vast tracts of pasture land, especially in North Canterbury and Marlborough, where many farms soon supported extensive monocultures of up to 34,000 plants/ha. Infestations of scattered plants, many of which arose in newly sown pastures, were manually grubbed, and this technique remains the primary control method in New Zealand. During the 22-year period from 1966 until 1988, data collected in North Canterbury revealed a pronounced reduction in the population density of the weed to apparent equilibria of 2 and 5 plants/ha on "developed" and "undeveloped" land respectively (Bourdôt et al. 1992).

From Weed Solutions website:
http://www.weedsolutions.co.nz/taskforce/
Control costs are affected by:

- Labour costs ($20-$40/hour)
- Transport/vehicle costs (c.$0.78/km)
- Herbicide costs – Taskforce Herbicide - 20L drum $750 (+ GST), Taskforce Herbicide - 5L container $225 (+ GST).
- Herbicide application rate – Taskforce can only be applied to a place at a maximum application rate of 3L/ha (EPA guidelines). The maximum application frequency of Taskforce is once per year.

FAQs Taskforce info sheet:
Taskforce contains 745g/L of the active ingredient sodium flupropanate. Registered for the first time in New Zealand in 2011. Taskforce is very slow acting (no effect may be evident for 3-4 months) and for this reason, most regional councils are recommending that landowners and contractors use Taskforce and Glyphosate when spot spraying nassella tussock. This means that council officers can inspect your property as soon as your control work has been completed and see the sprayed nassella tussock plants dying.

WILDING CONIFERS

From DOC website:
http://www.doc.govt.nz/nature/pests-and-threats/common-weeds/wilding-conifers/ methods-of-control/

1. Helicopter use

One of the biggest challenges of dealing with wilding conifers is often the remote and mountainous terrain in which they grow. To cover a large area of scattered trees efficiently, helicopters are sometimes used to deliver people and tools to the trees.

2. Hand weeding

Small seedlings can be hand pulled or eased out of the ground with a tool. The smaller the seedlings are, the easier this is. Finding the seedlings is the main challenge but, once found, the control is straight forward. Volunteers are very useful for this work.

Shake the soil from the roots and place any available leaf litter over the site where the conifer has been pulled. Don't leave bare soil as this will encourage further conifer seeds to germinate.

3. Cutting

Medium size conifers can be cut down with loppers or an axe – most conifers will not regrow if all branches and needle formation below the cut are removed. If the stump is carefully cleared of all branches and needles, herbicide treatment of the stump may not be required.

4. Chain saw

Large size conifers can be felled with a chain saw. Felling wilding conifers rather than ring-barking is sometimes preferred for aesthetic and safety reasons.

5. Ring barking

Large size conifers can be ring barked. This method is an alternative to cutting down only when the trees will not cause a hazard to electricity lines or people when they finally fall. With a sharp chisel, axe or chainsaw make two deep parallel cuts into the sapwood right around the base of the plant.
Vigorous ring barking is required for conifers. Cuts should be no less than 5 cm apart and all the bark should be removed from between the cuts. This method is not always successful as a callous may grow to heal the wound, or the plant may resprout from the base. Herbicide is sometimes applied to reduce the risk of regrowth.

6. Herbicide control

Herbicides are used to reduce the risk of regrowth from a cut stump or ring bark, and when wilding conifers are inaccessible or the stands are impenetrable.

Types of herbicide control:

- Ground basal bark application An oil-based herbicide designed to penetrate basal bark has been developed and offers advantages over foliar spraying and more labour intensive methods of delivering herbicide internally to the trunk (such as ring barking, frilling or "drill and fill"). The herbicide is applied as a wide collar around the trunk.
- Aerial basal bark application using a lance Helicopters are sometimes used to apply herbicide via a nozzle on a long lance. This method is particularly useful for covering trees spread widely across the high country and can be the only practical way to control trees growing on cliff-faces.
- Aerial foliar application using a boom When wilding conifer forests become dense and extensive, application of herbicide to foliage from the air becomes the only economic control method. Removing wilding conifers before they get to this stage is preferable.

Effective herbicide formulations to control wilding conifers are still under development. See the latest information about appropriate herbicide formulations (external site) on the wilding conifer website.

Whenever herbicides are used, users are required to follow the instructions set by the Environmental Protection Authority and specified on the label. This includes wearing the specified protective clothing.

From Landcare Research website:
http://www.landcareresearch.co.nz/publications/newsletters/biological-control-of-weeds/issue-63/controlling-wilding-pines

Herbicide

The new technology developed by Scion has involved developing a suitable cocktail of herbicides that have good penetration, uptake by the plants and mortality rates. "A combination of triclopyr and paraffin oil has been tested and is showing great results," says

Stefan. Up to 85% mortality has been seen in trees treated this way. Another advantage of this herbicide is that it can be applied outside of the growing season of the pines. The key to applying it is in the specially designed gun with a 1.5-m wand that can be operated from within a helicopter. The wand enables operators to spray the crown of the tree thus minimising the effects on surrounding vegetation. By eliminating the need to fell the trees, there is no physical disturbance to the surrounding vegetation, therefore reducing the chances of secondary weeds moving in such as gorse or broom. "The Department of Conservation is already using the new spraying system with success and expect there will be a significant reduction in operating costs as a result," confirmed Stefan.

From ODT website:
https://www.odt.co.nz/regions/queenstown-lakes/pine-control-method-may-reduce-costs

A new method of battling wilding pines could save millions of dollars on pine control in the next decade. The Department of Conservation has been testing new aerially sprayed herbicides to kill wilding pines on Queenstown Hill. The trial showed surprisingly positive results on one of the more troublesome species of pine, which has made DOC staff hopeful about potential savings.

Several experiments have been made in the fight against pines by spraying from the air, but the pines have been slow to absorb the poison, and the *Pinus contorta* variety especially appeared hard to eradicate this way.

For a 32ha area on Queenstown Hill, DOC biodiversity threats ranger Jamie Cowan tried mixing the usual herbicide with vegetable oil in an attempt to improve the trees' absorption of the herbicide. The spraying was done back in February, and the result is now showing. The addition of vegetable oil meant the targeted Douglas fir had died 30% quicker than in previous trials.

The new mixture also proved to have a significant effect on the sturdier and more invasive contorta pine. "It was a surprise to see that in less than a year the troublesome contorta variety in the area is also dying. This kind of pine is spreading drastically at many locations around the country, so finding a way to battle it is an important breakthrough.

"We will now be doing further trials with dense stands of *Pinus contorta* on the flanks of Coronet Peak near Queenstown and Mid Dome in Northern Southland," Mr Cowan said.

Cost-saving is one of the driving factors behind Doc's research in aerial spraying of pines. Spraying the 32ha at Queenstown Hill cost about $18,000 in total, or less than **$570 per hectare**, which was split between Doc, the Queenstown Lakes District Council and private landowners.

Mr Cowan said it cost **$2000-$3000 per hectare** to clear the pines by conventional methods of tree felling and manual weeding.

Mt Aspiring Station owner John Aspinall, a trustee of the Mid Dome Wilding Trees Charitable Trust, is optimistic about the prospect of cheaper pine control. "In the past, we have spent up to **$2000 per hectare** clearing pine growth with chainsaws, and as much as

$4000 per hectare to completely clear and mulch a pine area. We have an area of almost 250 ha of dense contorta pine growth at Mid Dome, so if the aerial method proves effective, we could be looking at substantial savings.

From Ledgard 2015:
Estimating affected areas and control costs
The predictable nature of wilding spread lends itself to more ready management, with known control costs, so that there is general agreement about the most appropriate methods of control and their costs per hectare. However, there is still uncertainty about what comprises ‘affected areas’ and their extent. Some affected areas are obvious due to their close association with known seed sources, and in these the costs of monitoring and control can be reasonably accurately calculated. But there are many other more extensive areas where there is a more variable rain of seed and hence invasion events are less frequent. It is these that can create big variations in cost calculations, as their extent is difficult to estimate. Even though the wilding density might be well below 1/ha, the areas can be included in the total 'affected area' figure and then ascribed the average control cost for 'scattered outliers' - even though the real control cost is likely to be much lower. In addition, a definite contribution to control costs is the current need to helicopter fly the whole area to find the outliers. Relative to this search cost, DOC and Scion are working on a system where such areas can be flown with fixed wing aircraft using high definition, remote sensing equipment, which can not only pick up seedlings down to 0.5m tall, but also determine species. This would considerably reduce search costs and enable one-off control to be directed to specific sites.

POSSUMS

Control costs vary according to:

1. Type of operation (aerial vs ground-based)
2. Bait type (carrot, cereal)
3. Possum density prior to operation
4. Bait density/sowing rate (usually varies from 2 to 40 kg/ha)
5. Pre-feeding (yes/no)
6. Monitoring costs (trap-catch rates)

Aerial

- Aircraft type
- Distance from base

Ground

- Terrain (km of traplines covered per hour/day)
- Accessibility, distance to site

From Warburton & Cullen 1995:
AERIAL CONTROL
Information from 15 aerial 1080 operations by DOC, undertaken over areas which ranged from 101 to 18,000 ha, indicated that total **control costs varied from $8 to $54/ha** (with bait contributing the largest proportion of cost). Significant cost savings can be made by reducing high sowing rates (10+ kg/ha) down to 4-5 kg/ha with no apparent loss in effectiveness.

Cost of carrot bait ($90/tonne) is significantly less than cereal bait ($1690/tonne; mean from 11 operations). Cereal bait costs/tonne ranged from $1448-1876.

Sowing rates affected **bait cost/ha** with cereal bait operations ranging from **$5.80** (sown at 4 kg/ha) **to $21.30** (sown at 11 kg/ha). There was no significant relationship between the sowing rate and percent kill achieved. The one operation that used screened carrot bait, which cost considerably less than cereal bait/ha, still achieved a percent kill (85%) similar to the mean kill achieved by the seven DOC operations using cereal baits (83%).

The type of aircraft used for bait application affects total operational costs, with aeroplanes being cheaper than helicopters e.g. **$1.90/ha** for sowing by fixed-wing and **$5-11/ha** for sowing by helicopter. Larger operations often used both types of aircraft and had aircraft costs of about **$2-3/ha**.

Planning costs varied markedly as a percent of the total costs (1-20%), but were more consistent when considered on a per hectare basis (**$1-$3/ha**). One operation cited very low planning costs ($0.2/ha), but as this operation had been run jointly with a Regional Council bovine Tb operation, most of the planning was covered by Local Government funding.

The percentage of the control budget spent on monitoring (primarily percent kill) ranged from 5-34% or $2-3/ha. About 10-12% (**$2-3/ha**) of control budgets is often allocated to monitoring.

Contracting out the field operation to other organisations reduced the time commitment of DOC staff to control operations, but did not appear to reduce control costs (**$25 & $26/ha** using cereal baits).

Miscellaneous costs, which included items such as notices, first aid and safety equipment, and mileage, varied from **$1-3/ha**. The main contributor to this cost was vehicle mileage, which varied greatly between control operations depending on the distance of the control areas from accommodation.

GROUND CONTROL

Information on hunter-based possum control operations was available for 19 operations from four conservancies. The size of the areas controlled varied from 1.5 ha to 14 122 ha.

For the 10 areas of less than 1000 ha controlled by hunters under contract, total cost varied from **$14 to $62/ha**. Percent kill data available from seven of these operations ranged from 72% to 90%. There was no significant relationship between cost/ha and percent kill.

The cost/ha paid to contractors varied from $9-$44, but also had no significant relationship with the percent kill achieved. Similarly, there was no relationship between the cost/day of the contractor ($84 - $182) and the hectares covered per day (2.7 - 41.8) or between the cost/day and percent kill achieved. Costs to DOC associated with operational planning varied from $1 to $19/ha, and in two operations planning costs exceeded contractor costs.

Bay of Plenty Conservancy used Conservation volunteers to carry out possum control in several small reserves (Appendix 10.5). In these areas, control costs were higher (**$29 -**

$185/ha) than when contract hunters were used. The higher costs of these operations were partly a result of the small size of the areas controlled (1.5-11.4 ha). Small areas have disproportionately large planning and logistical costs, and may obscure any potential reduction of costs gained from
using volunteer hunters.

The area covered per day of hunting in all ground operations ranged from 0.1 to 41.8 ha. In the largest blocks where relatively large areas were covered per day it appears that the actual area covered (effective area) may be less than the total management area. Operations with low areas covered per day were all small (<5 ha), and presumably a large portion of a day was spent travelling to and from the control area. For areas greater than 100 ha, about 10-15 ha were covered per day to achieve an 80%+ kill.

COMPARISON

On average, the cost and effectiveness of aerial and ground operations appeared similar. Aerial operations, that used cereal baits against 1080-naive possums cost c. **$30/ha**, and resulted in an average population reductions of 83%. By comparison, the average cost for ground control (excluding operations using Conservation volunteers and the 3 large areas with exceptionally low costs/ha) was **$35/ha** and also resulted in an average population reduction of 83%.

From 1080: The Facts website:

AERIAL CONTROL

An aerial 1080 operation (including pre-feeding) costs **$12 to $16/ha**. Due to economies of scale, aerial delivery is cost-effective than ground operations. Average sowing rates of 1080 cereal baits have also declined significantly from over 30 kg of bait per hectare in the 1950s to under 2 kg of bait per hectare today.

Despite using 60% less 1080 bait (1 kg/ha), the reductions in possum activity indices achieved with cluster sowing (98.4%) were similar to those achieved with broadcasting sowing (97.8%).

GROUND CONTROL

With the average coverage area of only 4,000 hectare for each operation, ground baiting is not as time efficient as aerial operations.While ground operations may provide greater control over the operation, they are costly. The costs vary from **$4/ha** in easily accessible land to **$80/ha** in areas with difficult vegetation cover.

From Speedy 2003:

Aerial application of 1080 baits was the most time, operational and cost effective method, taking 8 days to achieve a 0.17 percent RTC (a 99.05% reduction) at a cost of **$26.25/ha.**

Of the four ground treatment methods, 1080 in bait stations was the most operationally effective taking 115 days to achieve a 1.32 percent RTC, a 93.66 percent reduction. However, at **$43.45/ha** this was less cost effective than other ground based methods.

Method	**Total Area (ha)**	**Labour Costs** ($20 per hour)	**Bait Costs**	**Vehicle Costs** (62 cents per km)	**Helicopter Costs** ($1,200 per hour)	**Re-Monitor Costs** ($350 per line)	**Total Cost per Hectare**
1080 bait stations	1,016	1,600 hours	1 tonne RS5 pre-feed ($2,038)	6,200 km	Nil	Two lines	**$43.45**

		$32,000	0.4 tonne 0.15% w/w 1080 RS5 ($2,638) 250 bait stations at $10.00 each 260 bait stations at $7.75 each Total $7,610	$3,844		$700	
Cholecalciferol bait bags	1,003	1,030 hours $20,600	15,000 pre-feed baits at 20 cents each 10,000 toxic baits at 74 cents each Total $10,400	4,960 km $3,075	Nil	10 lines $3,500	**$37.46**
Feratox and trapping	1,068	1,147 hours $22,940	24,200 Feratox® pills at 57 cents each Total $13,794	3,309 km $2,052	0.83 hours $998	20 lines $7,000	**$43.80**
Contractors choice (Feratox®, trapping &dogs)	1,081	898 hours $17,970	29,170 Feratox® pills at 57 cents each Total $16,626	3,750 km $2,325	0.9 hours $1,078	Five lines $1,750	**$36.77**
Aerial 1080 bait application	1,073	211 hours $4,220	5.2 tonne pre-feed carrot 5.2 tonne 0.08% w/w 1080 toxic carrot Total standard bait $4,641 Total deer repellent bait $11,079	1,308 km $811	9.6 hours $11,520	Nil	**$20.25** **$26.25***

* With deer repellent.

Notes

The average possum density in the North Island is 4/ha, but can reach 25/ha on pasture bordering areas of native forest and shrubland.

Annual control costs by landowners:

- Auckland Council (2016) $102,908-$1,900,081 over 165,250 ha = **$0.62-$11.50/ha (**Containment Control)

RABBITS

Annual control costs by landowners:

- ECan (2016) Low density to High density infestation **$0-200/ha**.
- Auckland Council (2016) **$60-157/ha.**
- Hawkes Bay RC (2015) Sustained Control **$15-30/ha.**

REFERENCES

Anon. 2016. *1080: The Facts. A joint Federated Farmers – Forest and Bird initiative.* http://www.1080facts.co.nz/1080-bait-and-delivery.html. Accessed 31 October 2016.

Kriticos D.J., Lamoureaux S., Bourdôt G.W. and Pettit W. 2004. Nassella tussock: current and potential distributions in New Zealand. Weeds of the Environment. *New Zealand Plant Protection* 57:81-88.

Ledgard N. 2015. Overview of wilding affected areas in Otago Region. Prepared for Otago Mayoral Forum (Queenstown Lakes, Central Otago, Waitaki, Dunedin City and Clutha District. 29 pp.

Speedy C. 2003. Hatepe Trial - Comparison of Ground and AerialTb Vector Control Methods. EPRO Research report. 53 pp.

Warburton B. and Cullen R. 1995. Cost-effectiveness of different possum control methods. *Science for Conservation 4*. Department of Conservation, Wellington. 17 pp.

Appendix B Biological characteristics

B1 Dispersal parameters and the contribution of a neighbour to pest infestations

Most pests animals and plants are excellent dispersers. This means that, in most circumstances, a pest infestation on a neighbouring property is capable of dispersing propagules far over the fence. How far depends on the number of propagules produced (be they seeds or juvenile possums) and the shape of the dispersal curve (most propagules travel a short distance but some travel far). The shape of this dispersal curve is a pest species' dispersal kernel. The distance from a neighbouring boundary that pests may spread can therefore be modelled with existing dispersal kernels from the ecology and biosecurity literature.

However, things are not that simple for assessing good neighbour rules. Because pests are excellent dispersers, we must also assess whether pests establishing on a property come from a neighbouring infestation or elsewhere. The greater the distance from a neighbouring fence line, the more likely a newly arrived pest did not come from the neighbouring property. The more common a pest is in the wider landscape, and the more effective its long distance dispersal, the less certain it becomes that new pest incursions on a property come from a neighbour and not elsewhere. In these cases, the imposition of wide boundary control rules on neighbours is both ineffective and unfair.

We account for these two processes by modelling the dispersal of pests from source populations both at the neighbour boundary and also from infestations further away. The boundary distance sensible for a "good neighbour" boundary control rule is a combination of how far propagules from the neighbour are likely to disperse and how far away from the boundary these propagules get diluted by propagules from the wider landscape.

In our model, we use a 90% certainty threshold that propagules establishing on a property come from a neighbouring infestation and not the wider landscape. Somewhat counterintuitively, this threshold is closer to the boundary for common and better dispersing pests (Fig 1) than for rare and more poorly dispersing pests (Fig 2).

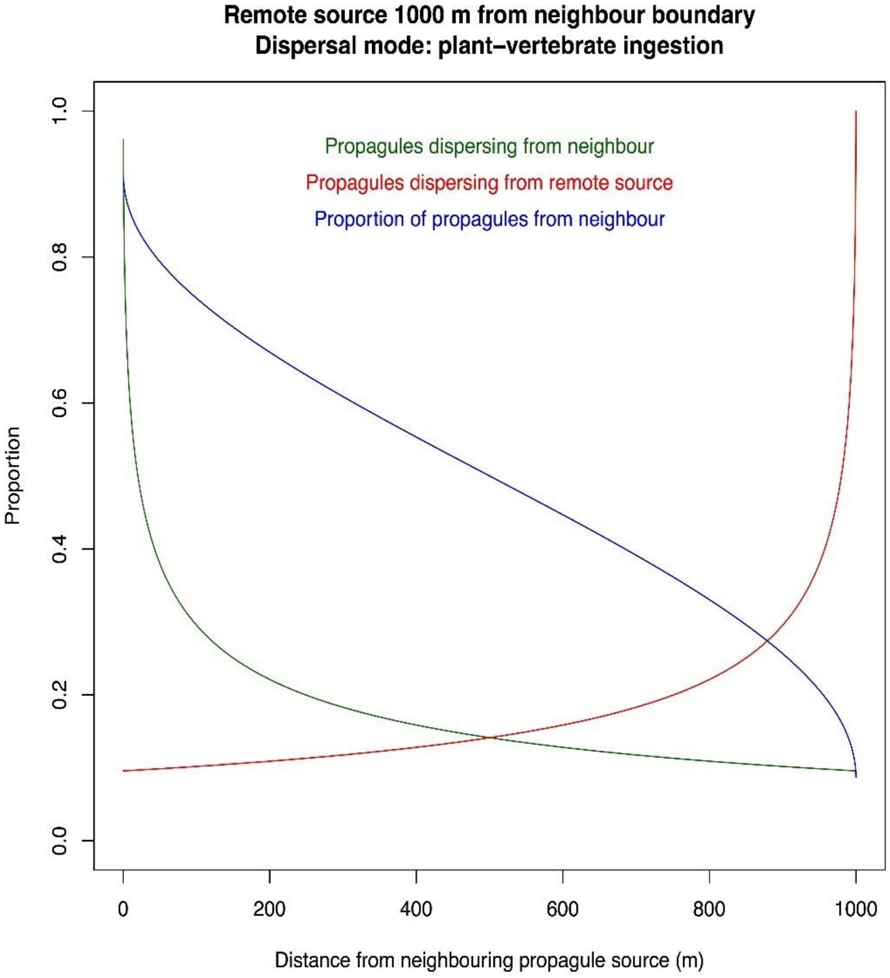


Figure 1: Lognormal dispersal curves from a neighbour boundary and an equivalent infestation 1 km away for a weed dispersed by animals (e.g., bird-dispersed). The parameters for these curves are in Table 1. This is a scenario with a well-dispersing abundant pest. Since 99% of seeds disperse up to 20 km, it is only 0.7 m away from the boundary after which less than 9/10 seeds come from the neighbouring infestation. At 500 m, half of the seeds are coming from the neighbour. In a case like this, it is unlikely that a boundary rule on a neighbour would be effective at reducing a pest.

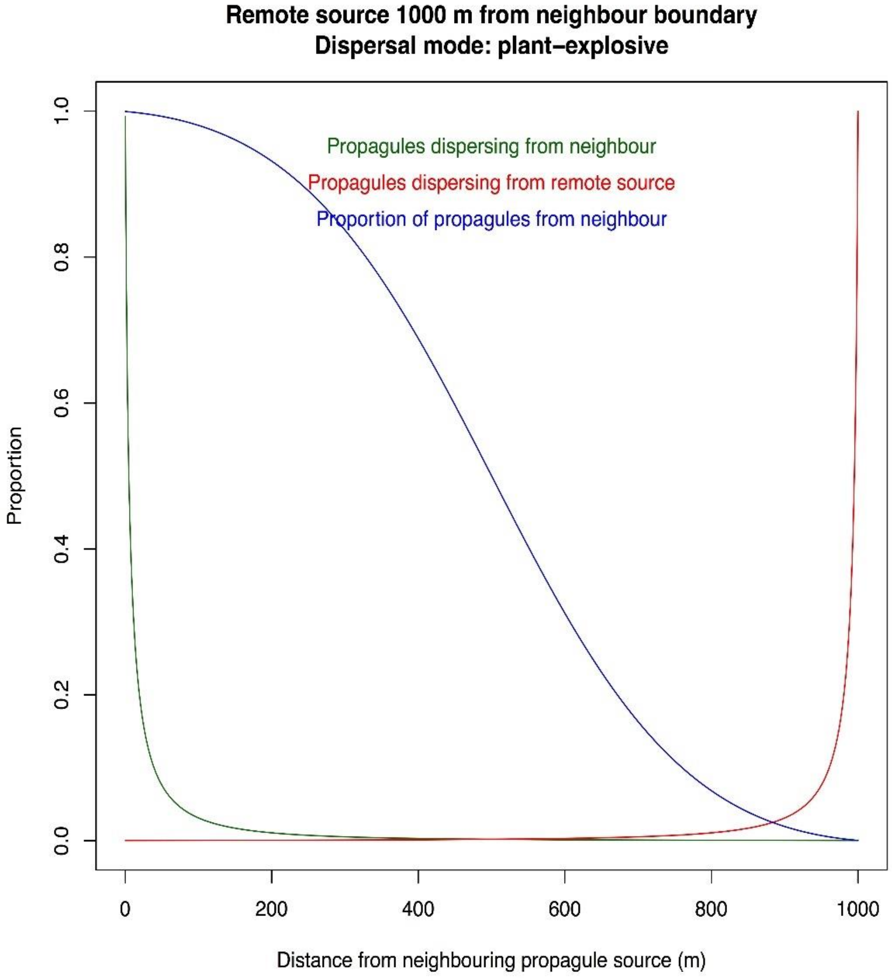


Figure 2: Lognormal dispersal curves from a neighbour boundary and an equivalent infestation 1 km away for a weed dispersed explosively (e.g., Scotch broom, which flings its seeds when its dried capsules explode). The parameters for these curves are in Table 1. This is a scenario with a poorly-dispersing but abundant pest. 99% of seeds disperse up to 210 m, and it is not until 231 m that less than 9/10 seeds come from the neighbouring infestation. A 210 m boundary rule in this case could be reasonable (although note in the case of Scotch broom, there can be considerable secondary dispersal of seed on stock and vehicles in agricultural environments).

To model the dispersal of pest propagules into a property, we use a lognormal dispersal curve, a mathematical distribution commonly fitted to dispersal data where many propagules disperse short distances from an infestation and few disperse far. We include parameters for five dispersal modes, "plant-gravity", "plant-explosive", "plant-wind", "plant-vertebrate ingestion", and "terrestrial mammal”. Table 1 shows the mean and standard deviation of the lognormal distribution applied to each of these dispersal modes, using average values extracted from the scientific literature (e.g., Smale 2014).

Table 1: The default dispersal parameters used in the model for different dispersal modes, fitted to a lognormal dispersal curve. The shape of the lognormal curve, often fitted to

dispersal data, has most propagules travelling a short distance and some travelling a great distance. For example, in the “plant-wind” dispersal mode, a lognormal curve with these parameters has 1% of seeds travelling more than 20 km.

Dispersal mode	Mean (m)	Standard deviation (m)
plant-gravity	1	5
plant-explosive	5	5
plant-wind	10	10
plant-vertebrate ingestion	20	20
terrestrial mammal	100	50

The exact dispersal parameters will vary among species and landscapes. However, estimating these values would require considerable field work and the model is more sensitive to how far away non-neighbour propagules are dispersing from, and how many there are. That information is unlikely to be known in most instances where this tool is being used. For the purposes of a decision making tool, our categories of dispersal mode sufficient should prove sufficient, in combination with varying the abundance parameter. This is especially the case when a variety of dispersal and abundance parameters all provide the same conclusion about whether a good neighbour rule is cost beneficial for a particular case.

To assess the relative contributions of a neighbouring infestation and infestations further off in the landscape to propagules landing at a site, we model dispersal of propagules from the neighbour boundary and from equivalent infestations 1 km and 10 km away. These are the scenarios for rare and common pests in the landscapes.

For each dispersal and pest abundance category, we then calculate the distance from the neighbour boundary within which we can be certain that 90% of propagules come from the neighbour. We also calculate the distance within which 99% of propagules from the neighbour will disperse. The minimum of these two distances is the recommended boundary distance, within which pests are likely to establish from the neighbouring infestation **and** at least nine out of ten pests are likely to have come from the neighbour.

B2 The time required for a newly established pest to reach near maximum impact on a property

Pest propagules arriving at a property don't immediately have high impacts on that property. Some pests, like wilding pines, take several years before they have serious impacts on land they invade. We need to account for this delay in our costing of impacts.

The exact time a pest takes to reach its maximum impact depends on a variety of factors, include the pest's biology, the environmental conditions at a site (e.g., climate), and how the pest impacts on the productivity (or other values) of the site. Estimating these factors precisely and accurately for any particular case would be expensive. Instead, we provide imprecise but still generally accurate estimates based on pest life form. Faster growing pests will reach near to their full impact much sooner than slow growing pests.

Pest mammals can have impacts soon after arrival (e.g., it only takes one possum infected with bovine TB to have high impact). Weeds, in comparison, are more varied in how long it takes them to reach high impact. Table 2 contains our parameter estimates for different weed life forms. When a pest is rare in the landscape, we have aded five years on to the values to account for how much slower a site will fill in with propagules.

Table 2: The approximate time in years that it takes weeds of different life forms to reach near to (~90%) of their maximum impact. On average, herbaceous perennials with vegetative spread, like tradescantia or tussock hawkweed, reach their maximum impact on a site quicker than herbaceous perennials that only spread by seed. Short-lived woody weeds are mostly be shrubs and vines, and long-lived woody weeds are trees.

Weed life form	**Vegetative spread?**	**Abundance**	**Years to 90% of max. impact (approx.)**
Herbaceous annual	No	rare	6
Herbaceous biennial	No	rare	7
Herbaceous perennial	Yes	rare	8
Herbaceous perennial	No	rare	10
Short-lived woody	No	rare	15
Long-lived woody	No	rare	20
Herbaceous annual	No	common	1
Herbaceous biennial	No	common	2
Herbaceous perennial	Yes	common	3
Herbaceous perennial	No	common	5
Short-lived woody	No	common	10
Long-lived woody	No	common	15

Appendix C Specific information on possum density and dispersal

Possum densities and dispersal (immigration) rates
Melissa Hutchison, Wildland Consultants
November 2016

From PCE (1994)

Table 2.1 Possum population densities and associated risk.

Habitat	Density: possums/ha	Conservation Risk	Tb Risk	Other Risk
Mixed forest-scrub-pasture margins	5 - >15	medium	very high	
Tree-lined waterways on farmland	5 - 15	low	high	
Small isolated forest patches	5 - 15	medium - high	medium	Loss of tourism income with reduced biological/landscape diversity
Rata/kamahi and mixed hardwood forests	5 - 15	high	low	Loss of tourism income with reduced biological/landscape diversity
Lowland indigenous podocarp forests	2 - 5	low	low	
Alpine shrublands	2 - 5	low		
Exotic forests	1 - 3		low	Browsing of young trees, (increased cost of planting)
Beech forests	< 2	low	low	
Alpine grasslands	< 2	low		
Open pasture and cropland	< 2		high	Loss of farm production with pasture/crop consumption by possums
Erosion plantings	?		medium	Browsing of plantings: an increase in localised soil erosio
Horticultural/ ornamental crops	?			Lost production (generally localised)

Density source: Department of Conservation, 1994(a), p.1; Cowan, 1991, p.75.

From Cowan (2000)

Factors influencing re-infestation

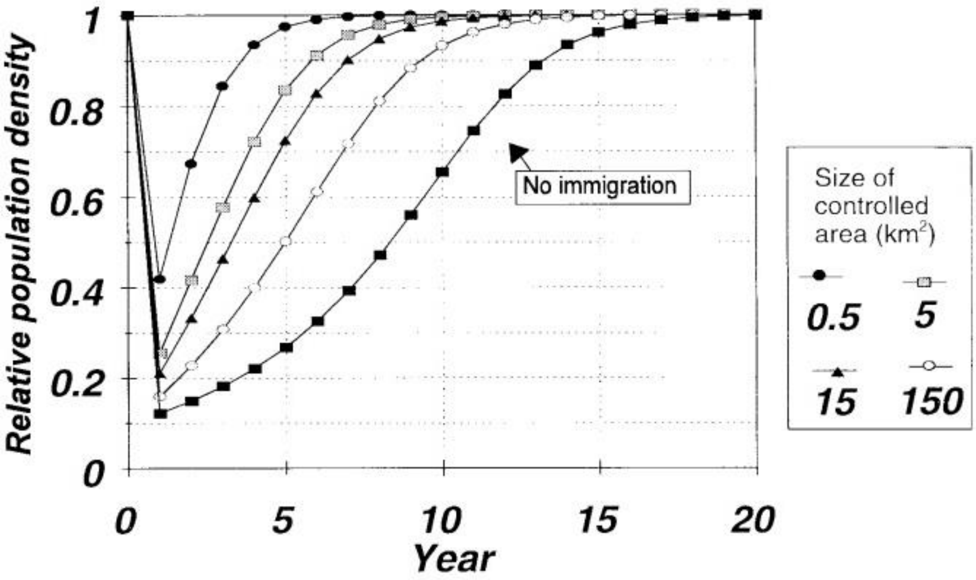
Factors influencing rates of re-infestation are of two types: those affecting immigration into an area subject to possum control; and those affecting the rate of recovery of the surviving possum population.

Immigration

The number of migrants arriving at a site is partly determined by site size the larger the site the larger the number of immigrants likely to arrive there (Appendix 1). Shape is also important for two sites of equal area, simple geometry shows that the one with the larger width at right angles to the source of dispersers would be likely to receive more migrants.

Patch size has a marked influence on the contribution of immigration to rate of recovery (Figure 2). For example, as patch size increases from 0.5 to 150 km^2 the time taken for numbers to increase to 50% of original density after an initial reduction of 90% increases from about one year to five years. In the absence of immigration, the population takes about eight years to recover to half its original density.

Figure 2. Effects of immigration and size of controlled area (from 0.5 to 150 km^2) on recovery of possum numbers in a homogeneous habitat after a single 90% control operation (Barlow model, r = 0.2; Barlow 1991).



Distance between habitat patches

Information on the effect of distance between habitat patches on immigration can be derived from studies of possum movements. **Local movements between habitats (<2 km) appear to be rare in uncontrolled populations**, and such movements would hence be expected to make little contribution to immigration. Brockie et al. (1989) live-trapped, marked, and released about 500 possums in contiguous swamp, willow and pasture habitats within a 300 ha area in Hawkes Bay over five years. Only 1-2% of animals first trapped in one habitat were recaptured in a different habitat. Similarly, Cowan & Rhodes (1993) found that there were few movements of possums between bush patches on adjacent farms in the central North Island and **only 10% of them were of more than 500 m**.

Three factors contribute to these findings:

- Adult possum home ranges generally change little in size or activity centre over the animals' lifetimes (Ward 1978; Brockie et al. 1989; M.G. Efford unpubl.).

- The nightly distances (range lengths) moved by possums are generally not large, ranging from **100-200 m in forest to about 2 km** at the extreme where animals are foraging from forest out onto farmland (Green & Coleman 1986) or over extensive areas of pasture (Brockie et al. 1989).
- Long distance movements (>2 km) by possums are almost only made by juvenile animals, mostly males (Efford 1991; Cowan et al. 1996). **Average dispersal distance is about 6 km, reducing to 5 km** if the three extreme movements of 25, 31, and 41 km are excluded.

The percentage of possums dispersing over a particular distance decreases sharply as the distance increases (Figure 4).

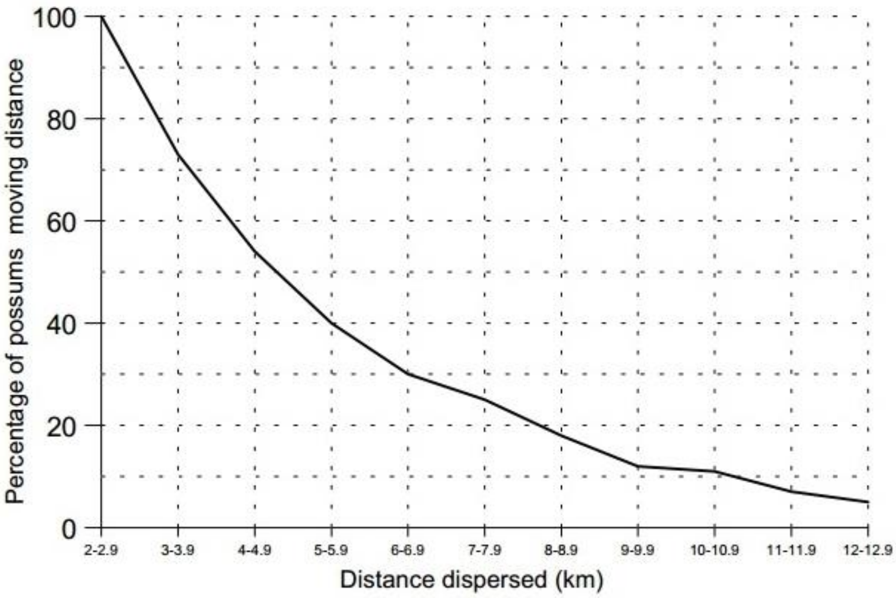


Figure 4. Percentage of possums dispersing over various distances (Cowan unpubl.). Dispersal was defined as a movement of >2 km to distinguish it from large local movements about an animal's home range (Clout & Efford 1984).

The number of immigrants arriving at a site (dispersal sink) after control is affected by a number of factors (Figure 5).

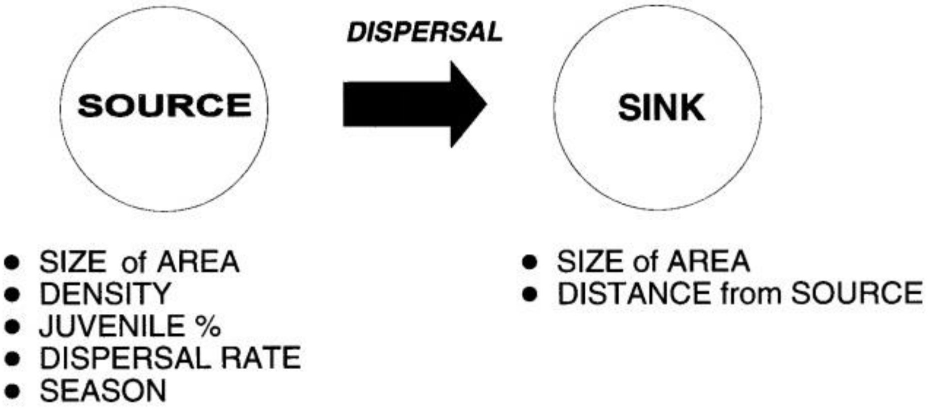


Figure 5. Factors affecting animal dispersal at source and settlement at sink.

About 20-25% of juvenile possums undertake long-distance dispersal (Cowan & Rhodes 1993; Cowan et al. 1996, 1997), and juveniles at peak numbers make up about 30% of the possum population (Efford 1996).

Effects of control on immigration

One explanation for the rapid recovery of possum numbers after control is the suggestion that possums from surrounding uncontrolled areas rapidly invade the controlled area because there is reduced competition for food and den sites in the controlled area. This is often referred to as the vacuum effect. There is little evidence to support this idea. Cowan & Rhodes (1993) found that only one out of 78 radio-tagged possums shifted its daytime location after a nearby aerial 1080 control operation, even although about half of the possums were within foraging range of the controlled area where density had been reduced by about 80%. Brockie (1991) tagged 141 possums at scrub patches within 3 km of two adjacent farms where about 90% of possums had been killed. Only one of these, a juvenile male on first capture, was trapped on the controlled farms over the subsequent two years. Efford et al. (2000) found effectively no new possums arriving in a 13 ha bush remnant on farmland during the 12 months after possum numbers in part of the patch had been substantially reduced. There was some local shifting of home ranges by survivors adjacent to the controlled areas during the 12 months after the control operation, however, the effect was only detectable over a distance of 200-300 m and seemed to involve animals whose ranges overlapped the control zone (Efford et al. 2000). Where the process of population recovery after control has been studied in detail (Clout 1977; Green & Coleman 1984; Cowan unpubl.), it has been found consistently that the initial immigrants are largely young animals, mostly males, suggesting that they arrived as a result of dispersal movements rather than local range shifts.

Possum numbers appear to build up after control more quickly in preferred than less preferred habitats. Forest/pasture margins often hold very high numbers of possums and recovery of numbers there after control is often more rapid than in other habitats. Coleman et al. (1980) estimated possum densities on Mt Bryan Westland, at 25 per hectare along the forest/pasture margin, which decreased progressively with altitude to 1.9 per hectare in the high altitude forest. Three years after possums were eradicated, numbers had recovered to about 50% of pre-control in both the forest/pasture margin and higher up in the bush, so that the margin again had much higher possum numbers. Hickling (1993) and Caley et al. (1995) found that under annual maintenance control for Tb management, **possum numbers along forest/pasture margins increased more rapidly than did those within the forest**. Relative to initial numbers, there was no marked difference in rates of recovery between habitats in these studies, but in absolute terms possum numbers increased most rapidly in the initially highest density (preferred) habitats.

Buffer zones

One strategy to reduce the rate of immigration into a target area is to reduce possum numbers in the immediately surrounding area, to create a low-density buffer zone around the target area. Buffer zones could reduce re-infestation because they contain fewer possums and hence produce fewer dispersers. They may also reduce re-infestation by encouraging dispersing possums to settle in them rather than continue to disperse and potentially colonise the target area because they offer reduced competition for food and nest sites. Barlow (1993) modelled the use of buffer zones to reduce re-infestation and concluded that they were effective more **because they reduced the number of dispersing animals from the buffer zone than because they intercepted dispersers and acted as dispersal sinks**.

Rate of recovery of surviving populations

Population reduction

The extent to which a population is reduced by control has a marked effect on its rate of recovery in the absence of immigration. For example, reducing the initial kill from 90% to 70% reduces the time for the population to recover to half its original density from about eight years to about three years (Figure 6). With rate of increase (r) > 0.2 or with immigration these times would be greatly shortened, but the effect of the higher initial kill in slowing population recovery would remain.

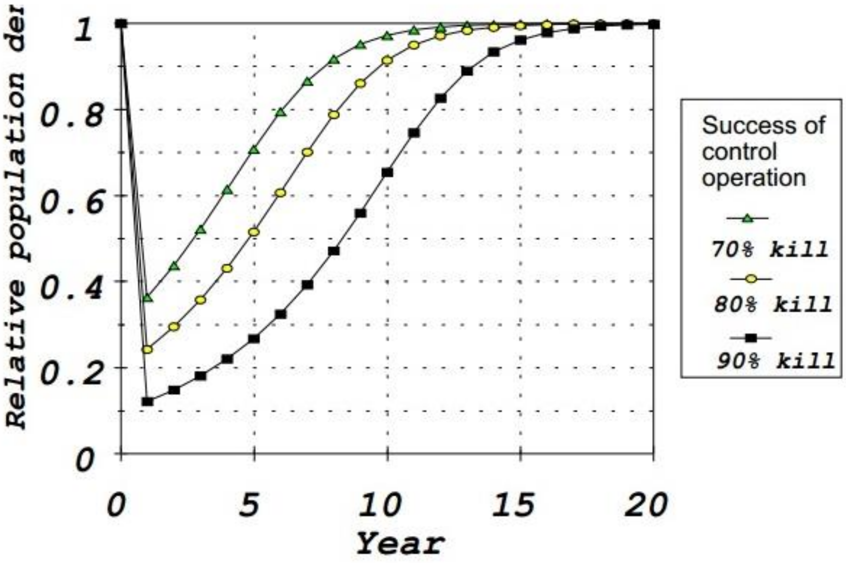


Figure 6. Recovery of possum populations after various levels of kill, from a single control operation, in a homogeneous habitat, in the absence of immigration (Barlow model, r = 0.2; Barlow 1991).

From Byrom *et al.* (2015)

"in New Zealand they can reach population densities exceeding 10 animals/ha in the most preferred forested habitats where individual animals' home ranges are usually <5ha."

Factors affecting possum movement

For the foreseeable future, TB management in some places in New Zealand will rely on continued expenditure to maintain buffer zones. The **cost per control operation is directly proportional to the area of those buffers**. **Accordingly, buffer widths should be as small as possible to minimise the costs of control.** Another cost-reduction measure would be to expend greatest control effort in areas where long-distance movement by possums is most likely. In relation to buffer zones these are unknown; however Arthur et al. [14] suggested that the vacant habitat of possum-depopulated zones might attract possums into it by changes in the animals' movement patterns in response to low-density environments. **Possum movement from an untreated area (typically high possum density) into or through an adjacent buffer zone (zero to low density) is most likely to occur during the annual (or biannual [9]) dispersal of sub-adult animals** [5]. In addition, landscape attributes (e.g. river courses, gorges or high ridges) might restrict or channel possum movements and thus modify movement patterns. In this latter regard a recent study quantified the effort cost to possums of dispersing across a heterogeneous landscape [15], identifying rivers and elevation gradients as potential modifiers of movement.

The simulated un-controlled forested area with an infected possum population was a 3 km x 0.5 km forest block (infected block) with the long side adjacent to the recently controlled buffer. The number of infected possums in the infected block was the product of the density, area (1.5 km^2), and TB prevalence. Population density values were set at typical high and low levels of **9 and 2 animals per ha** for possums in this type of habitat [36]. The six buffer widths ranged between 500–3000 m in 500m increments.

From analysis of the GPS data, we found **no evidence that the directions of dispersal and exploratory movements were biased towards forest with reduced possum density (i.e. preferential movement of possums into vacant territory**), even though these provided habitat as suitable for possums as untreated forest. Further, we found no evidence that forested ridgelines changed movement patterns of possums, although our data did provide an indication that large rivers could act as barriers, resulting in possums moving primarily along valleys.

Overall, most possums (83.5% of all possums, 94% of adults and 65.5% of sub-adults) exhibited a settled home range pattern (Table 1). Sub-adults recorded outside their initial home range were divided approximately evenly (10–14%) between the other three types of movement.

Predicted movements across a buffer

Based on the GPS data, the most likely duration of a representative movement event (i.e. a period that included dispersal or a bout of exploratory movements) was 7 days, while 4 and 10 days represented low and high estimates of the duration of such events. The probability of a TB incursion event (i.e. at least one infected possum traversing onto farmland) varied mostly with buffer width, and to a lesser extent with the population density and prevalence of TB in the source possum population (Fig 3). The probability of incursion increased with increasing number of days of the representative movement event. However, if priority was given to maintaining a very low probability of incursion (e.g. < 0.01), the outcomes were similar across the range of days in the simulation**. In the best-case scenario**, where density was 2 possums ha-1 and TB prevalence was 0.02 (Fig 3D), **buffers of at least 2000m were not breached**, irrespective of the number of days over which the simulated representative movement event took place. In the intermediate risk scenarios (Fig 3B and 3C), **a 3000m buffer was predicted to be acceptable for all event durations**. In the **worst-case scenario** (i.e. one likely to produce the most pessimistic estimate of the effectiveness of a buffer), in which density was 9 possums ha-1 and TB prevalence was 0.1 (Fig 3A), **the 3000m buffer was predicted to be acceptable** (< 0.008 probability of TB incursion) if the duration of the representative movement event was less than 10 days. If a 10 day event was simulated in this scenario, the probability of incursion with a 3000m buffer increased to 0.031.

Pech et al. [13] compared rates of reinvasion by possums for a simulated ‘vaccine-protected’ buffer (i.e. a buffer zone with an intact possum population) with reinvasion rates for a buffer in which possums had been controlled by conventional means (i.e. a buffer zone in which the possum population had been reduced by poisoning). In that study**, there was relatively little movement of adult possums from native forest at carrying capacity (>3 possums/ha) into a forest buffer that had received recent possum control**: over the first 6 months of monitoring, **a poison-treated buffer c. 350 m wide was predicted sufficient to contain 95% of movements by adult possums, while a buffer c. 450 m wide would have been**

equally effective for an additional 6-month period. In the present study we also included subadult possums in our simulations, i.e. animals that (along with adults) were thought at the outset to represent the greatest risk of translocating TB during dispersal [27]; even then, modelling predicted that, for a region with low possum density and low TB prevalence, there would be a very low probability of TB incursion onto farmland during a representative possum movement event lasting 4-10 days. Since buffer widths used in practice for TB containment in forested areas currently range from 5-15km [8], the present results suggest there is scope for buffer widths to be reduced while still maintaining good protection against TB incursions due to short-term movements that typify possum dispersal or exploratory behaviour.

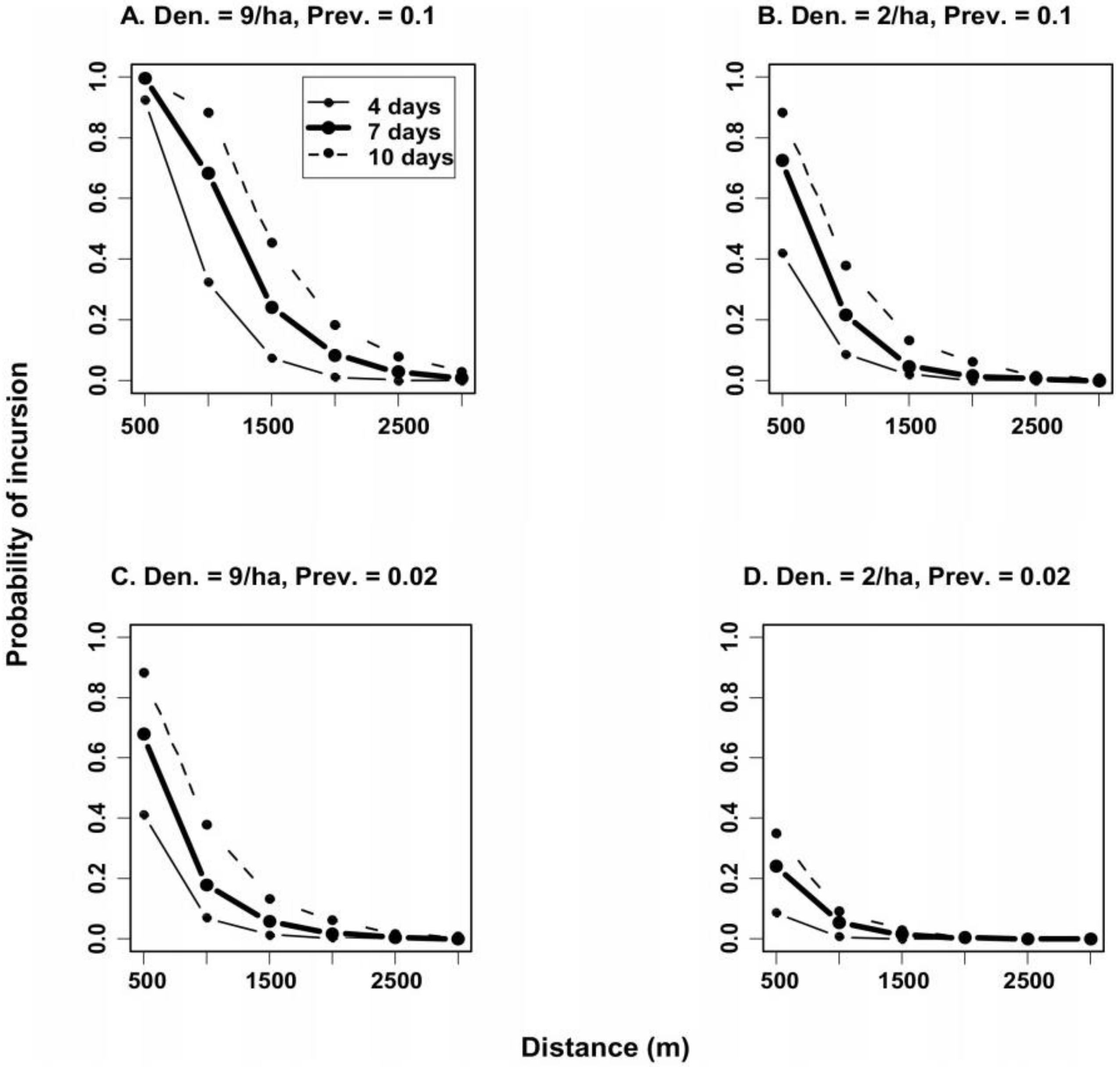


Fig 3. Predictions of the probability of a TB incursion event onto farmland (i.e. at least one *M. bovis*-infected possum crossing a buffer) during the period when most possum dispersal occurs. Simulations were run with buffer widths ranging from 500 – 3000m and with the following combinations of population density and disease prevalence in untreated forest: (A) density = 9 ha^{-1} and TB prevalence = 0.1; (B) density = 2 ha^{-1} and TB prevalence = 0.1; (C) density = 9 ha^{-1} and TB prevalence = 0.02; and (D) density = 2 ha^{-1} and TB prevalence = 0.02.

Possum-depopulated buffer zones continue to be used in New Zealand [8] to isolate a source of heightened infection risk (e.g. forested habitat containing possums with a recent history of TB) from a nearby asset (TB-susceptible livestock on farmland). **Our study suggests that the types of movement by possums (dispersal and exploratory movements) most likely to transfer M. bovis infection across a buffer are uncommon and that current buffer widths in New Zealand represent a risk-averse management strategy**. However, gaps remain in our knowledge of the epidemiology of TB (especially factors affecting disease transmission rates) in possum populations re-colonising a forest buffer. We further conclude that in establishing buffer zones for protection of livestock against wildlife TB there is potential to take advantage of natural features, such as large rivers, that can block possum movements and divert them to areas where more intensive control can be conducted.

References

Barlow N.D. 1991. Control of endemic bovine Tb in New Zealand possum populations: results from a simple model. *Journal of Applied Ecology* 28: 794–809.

Barlow N.D. 1993. A model for the spread of bovine Tb in New Zealand. *Journal of Applied Ecology* 30: 156-164

Brockie R.E., Herritty P.J., Ward G.D. and Fairweather A.A.C. 1989. A population study of Hawke's Bay farmland possums, *Trichosurus vulpecula*. Department of Scientific and Industrial Research, *Ecology Division Report* 26: 1-43.

Byrom A.E., Anderson D.P., Coleman M., Thomson C., Cross M.L. and Pech R.P. 2015. Assessing movements of brushtail possums (*Trichosurus vulpecula*) in relation to depopulated buffer zones for the management of wildlife tuberculosis in New Zealand. PLoS ONE 10(12): e0145636. doi:10.1371/journal.pone.0145636.

Cowan P.E. 2000. Factors affecting possum re-infestation: implications for management. *Science for Conservation* 144. Department of Conservation, Wellington. 23 pp.

Hughes H. R. 1994. *Possum management in New Zealand*. Office of the Parliamentary Commissioner for the Environment, Wellington. 203 pp.

Pech R., Byrom A.E., Anderson D., Thomson C. and Coleman M. 2010. The effect of poisoned and notional vaccinated buffers on possum (Trichosurus vulpecula) movements: minimising the risk of bovine tuberculosis spread from forest to farmland. *Wildlife Research* 37: 283–292.

Appendix D Biological characteristics – Weed seed bank decay models for weed species that are subject to a Good Neighbour Rule

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D1 Summary

Exponential decay models for the soil seed banks of 13 weed species were developed using data from published experiments in which the survival of buried seeds had been measured. The species are those that will potentially be the subject of a Good Neighbour Rule (GNR) requiring a neigbour adjoining land cleared of the weed to control the species. The species for which models were developed are the grasses *Nassella trichotoma* and *Pennisetum macrourum*, the herbs *Carduus nutans* and *Jacobaea vulgaris* (syn. *Senecio jacobaea*), the woody shrubs *Cytisus scoparius* and *Ulex europaeus* and the trees *Larix decidua*, *Pinus contorta*, *Pinus nigra*, *Pinus ponderosa*, *Pinus radiata*, *Pinus sylvestris* and *Pseudotsuga menziesii*. Three additional species wilding trees, *Pinus mugo, Pinus muricata and Pinus pinaster*, were also considered but no data could be found on seed bank longevity in these species and models could not be constructed. The models reveal large differences between the species groups in soil seed longevity. The grasses exhibited the fastest decay rates (mean = 83% year^{-1}) followed by the trees (72% year^{-1}), the woody shrubs (27% year^{-1}) and slowest, the herbs (17% year^{-1}). These results imply that a GNR will be easier to justify for the grasses and trees and increasingly more difficult for the woody shrubs and the herbs where long-lived on-site seed banks will be a dominant reason for an ongoing weed problem.

D2 Introduction

Simon Harris at Landwaterpeople (LWP), Christchurch, has been contracted by a collective of New Zealand Regional Councils to lead the development of a decision support CBA model for regional councils to analyse the benefits and costs for inter-regional pests to which a Good Neighbour Rule may apply. The proposal submitted by LWP to the collective was approved in September 2016 and the model development team (Simon Harris, Jon Sullivan, Melissa Hutchinson and Graeme Bourdôt) has developed a model framework and will determine the values of its parameters for each of the relevant inter-regional species (feral rabbits, possums, gorse, African feather grass, ragwort, nodding thistle, broom, nassella tussock and wilding conifers)

With respect to the weed species (2 grasses, 2 herbs, 2 woody shrubs and up to 10 trees), a key parameter in the CBA model is the rate at which their seed bank decays in the absence of ongoing seed inputs. Here we develop models to describe this process for each of the weeds for which data is available.

D3 Materials and methods

To find data suitable for modelling the seed bank decay (loss of seeds from the soil seed banks) for each of the weeds, a library search was conducted using the databases: CAB Abstracts 1973- ; CAB Abstracts Archive 1910-1972; Scopus. Search terms / keywords used were: seed, seedling, seed bank, soil, soil borne, survival, burial, longevity, decay, decline, mortality, recruitment, establishment, emergence, regeneration, spread, dispersal, invasive, weed, wilding, conifer, pine, *Pinus*, *P. muricata*, *P. nigra*, *P. mugo*, *P. ponderosa* , *P. radiata*, *P. contorta*, *P. pinaster*, *P. sylvestris*, *Pseudotsuga menziesii*, *Larix decidua*, *Nassella trichotoma*, *Pennisetum macrourum*, *Carduus nutans*, *Jacobaea vulgaris* (syn. *Senecio jacobaea*), *Cytisus scoparius* and *Ulex europaeus*.
Common names for each of the species were also included as search terms.

Data suitable for this purpose was found for 13 of the 16 weed species. The exceptions were *Pinus mugo, Pinus muricata* and *Pinus pinaster* for which the survival of soil-borne seeds has apparently not been reported. In each of the 13 cases, exponential decay models were fitted to the available data using Excel after first expressing sequential annual counts of seed numbers relative to the number of seeds that were buried at the start of the experiments. In some cases, e.g. broom, the author had provided the estimate of annual rate of seed loss which was used to contruct the models.

The model fitted to the data is:

$$y = 100e^{-rt},$$

where y is the percentage of seeds in a soil seed bank remaining after t years of burial and r is the exponential decay constant. The annual % loss (decay) of seeds is $(1-e^{-r}) \times 100$.

From the fitted models for each species, the time T_i (years) required for the seed bank to decline to i = 50, 20, 10 and 5% of its original size (number of viable seeds) was calculated as:

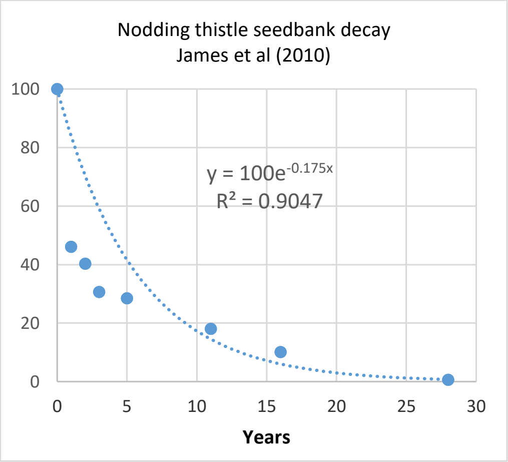
$$T_i = [\ln(i)-\ln(100)]/-r$$

D4 Results and discussion

Carduus nutans **Nodding thistle**

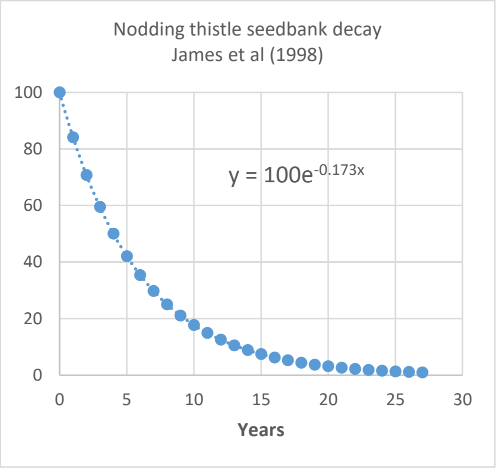
The model was fitted to *C. nutans* seed survival data obtained over 28 years from an experiment on two soil types under permanent pasture in New Zealand (James *et al.*, 2010). The soil types were Horotui sandy loam and Hamilton clay loam. The seeds had been buried at three different depths (1-20, 50 and 200 mm). The model was fitted to the averages over soil type and burial depth after first transforming the data to percentages of initial number of seeds buried.

The data and the fitted model is shown in the graph and the T_i values for 50, 20 10 and 5% survival are 4.0, 9.2, 13.2 and 17.1 years respectively.



In a second paper describing another experiment, *C. nutans* seeds were buried in four different New Zealand soils and the time (years) required for the seeds to decline to 1% of their original viability estimated (James *et al.*, 1998). Averaging these estimates over the 3 depths and four soils gave a mean of 26.6 years for the seeds to decline in number to 1% of their original number and the model was constructed accordingly.

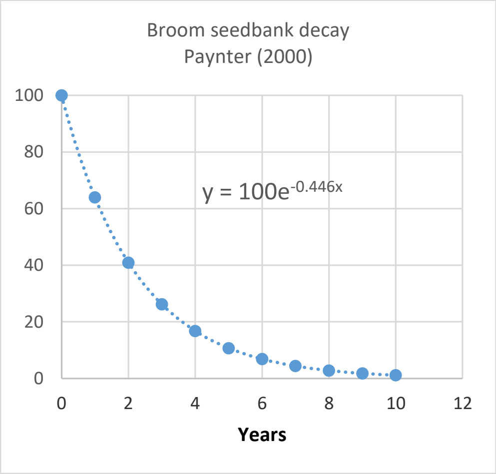
The model is shown in the graph and the T_i values for 50, 20 10 and 5% survival are 4.0, 9.3, 13.3 and 17.3 years respectively.


Nodding thistle seedbank decay
James et al (1998)
100
80
60
40
20
0
0
5
10
15
20
25
30
Years
$y = 100e^{-0.173x}$

Cytisus scoparius Broom

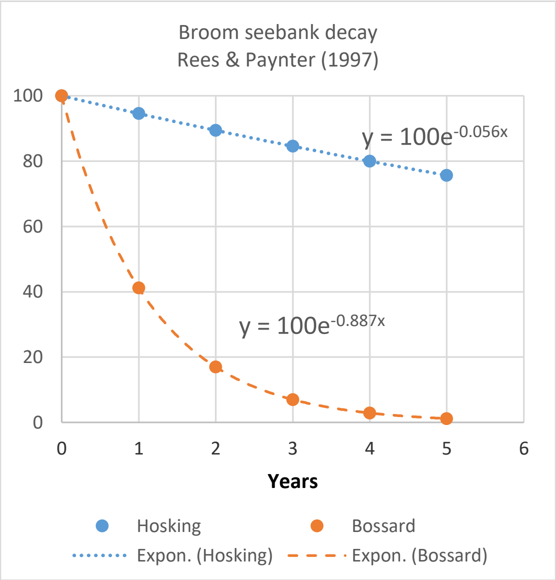
In an experiment in NSW, Australia, a 36% annual loss of seeds as was estimated for *C. scoparius* (Paynter, 2000) and this loss rate was used to construct the exponential decay model. No data could be found from experiments in New Zealand and we assume that the Australian study provides a suitable estimate of broom seed bank's decay in New Zealand.

The model is shown in the graph and the T_i values for 50, 20 10 and 5% survival are 1.6, 3.6, 5.2 and 6.7 years respectively.



During the development of a model for the abundance of broom, the authors noted "It is not clear how long broom seed banks persist" (Rees & Paynter, 1997). They referred to two studies (Hosking, Smith and Sheppard (1996) and Bossard (1993)) that provided very different estimates of the longevity of broom seeds in the soil; 80% of seeds still alive after 45 months and 7% of seeds remaining un-germinated 3 years after burial at 40mm. The exponential decay models for these two cases are in the graph below.

The T_i values for 50, 20 10 and 5% survival are 12, 29, 41, 53 years and 0.8, 1.8, 2.6, 3.4 respectively.



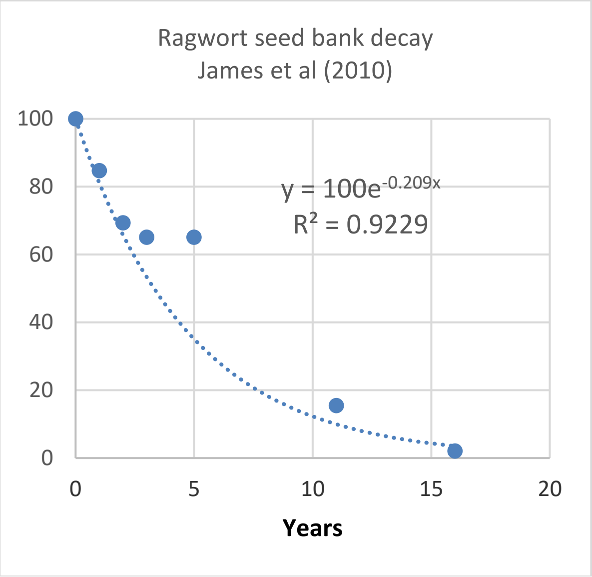
Jacobaea vulgaris*, syn. *Senecio jacobaea **Ragwort**

The model was fitted to *J. vulgaris* seed survival data obtained over 28 years from the experiment on two soil types under permanent pasture in New Zealand; the same experiment from which the nodding thistle data was obtained (James *et al.*, 2010).

The soil types were Horotui sandy loam and Hamilton clay loam. The seeds had been buried at three different depths (1-20, 50 and 200 mm). The model was fitted to the averages over soil type and burial depth after first transforming the data to percentages of initial number of seeds buried.

The data and the fitted model are shown in the graph.

The T_i values for 50, 20 10 and 5% survival are 3.3, 7.7, 11.0 and 14.3 years respectively.

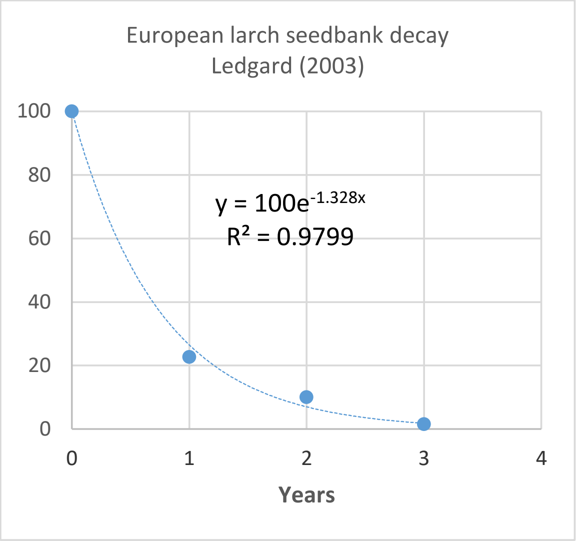


Larix decidua European larch

The model was fitted to *L. decidua* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003). The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model are shown in the graph.

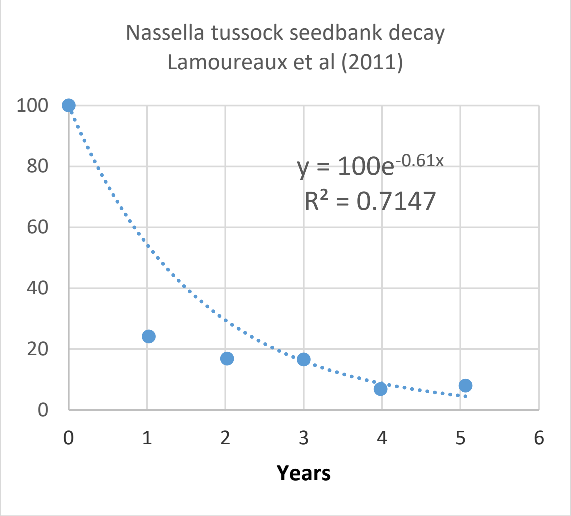
The T_i values for 50, 20 10 and 5% survival are 0.5, 1.2, 1.7 and 2.3 years respectively.



Nassella trichotoma **Nassella tussock**

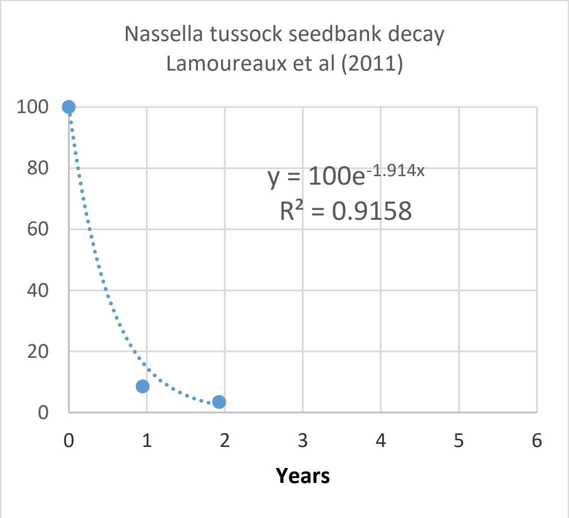
The model was fitted to *N. trichotoma* seed survival data derived from two separate experiments in North Canterbury, New Zealand in which viable seeds of the species were buried and exhumed and counted at intervals over five years (Lamoureaux *et al.*, 2011).

The data from the first experiment and the fitted model are shown in the following graph. The T_i values for 50, 20 10 and 5% survival are 1.1, 2.6, 3.8 and 4.9 years respectively.



The data from the second experiment and the fitted model are shown in the following graph. Data from the first 3, 6 and 9 months were omitted in fitting the model to avoid within year variation in decay rates influencing the annual decay rate estimation. Data for years 3, 4 and 5 were also omitted; they were spurious in that they indicated inexplicable increases with time in viable seeds (an artefact attributed by the authors to sampling errors (Lamoureaux *et al.*, 2011).

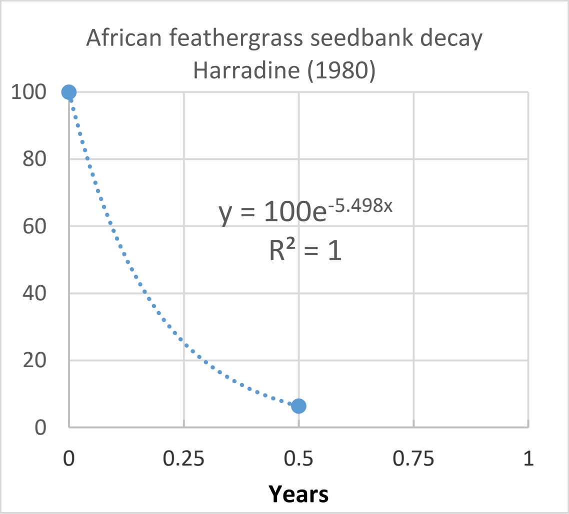
The data from the first experiment and the fitted model is shown in the following graph. The T_i values for 50, 20 10 and 5% survival are 0.4, 0.8, 1.2 and 1.6 years respectively.



Pennisetum macrourum **African feather grass**

No seed survival data from experiments conducted in New Zealand could be found for this species. The only data available was from a study in Australia in which the seeds of the species had been buried 80 mm deep in pots of a sand/peat mixture in a glasshouse and assesse for viability 6 months later (Harradine, 1980).

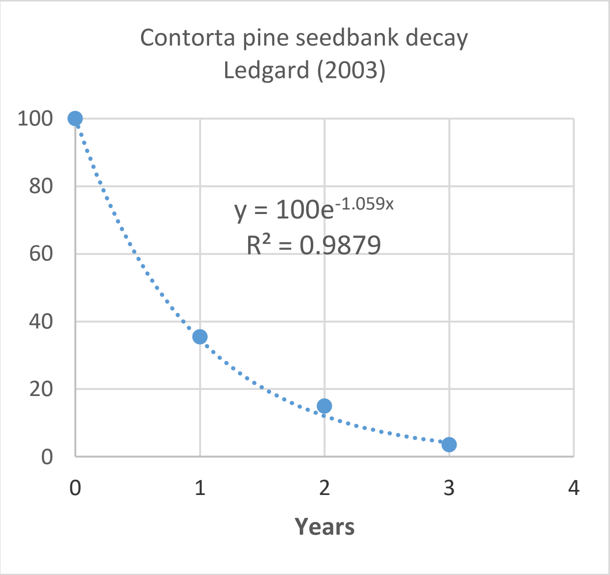
The data and the fitted model are shown in the following graph. The T_i values for 50, 20 10 and 5% survival are 0.13, 0.29, 0.42 and 0.54 years respectively.



Pinus contorta **Lodgepole or contorta pine**

The model was fitted to *P. contorta* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003). The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model are shown in the graph and the T_i values for 50, 20 10 and 5% survival are 0.7, 1.5, 2.2 and 2.8 years respectively.



Pinus mugo Dwarf mountain pine

No data could be found to model seed bank decay in *P. mugo* (Ledgard, 2003).

Pinus muricata Bishop or muricata pine

No data could be found to model seed bank decay in *P. muricata* (Ledgard, 2003).

*Pinus pinaster*Maritime pine

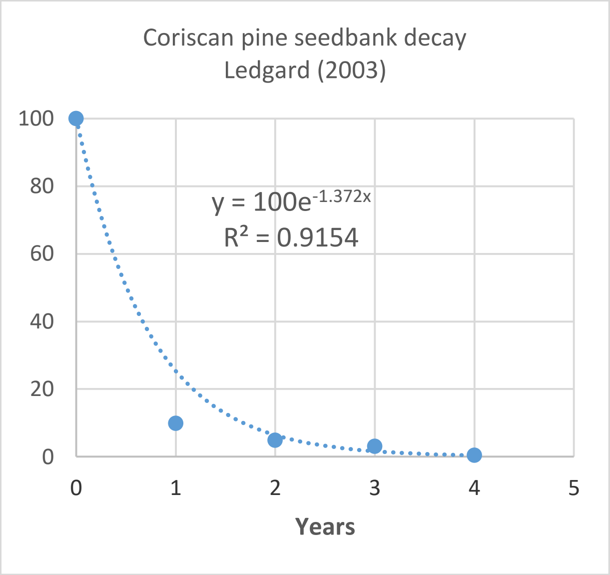
No data could be found to model seed bank decay in *P. pinaster* (Ledgard, 2003).

Pinus nigra Corsican pine

The model was fitted to *P. nigra* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003). The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model are shown in the graph.

The T_i values for 50, 20 10 and 5% survival are 0.5, 1.2, 1.7 and 2.2 years respectively.

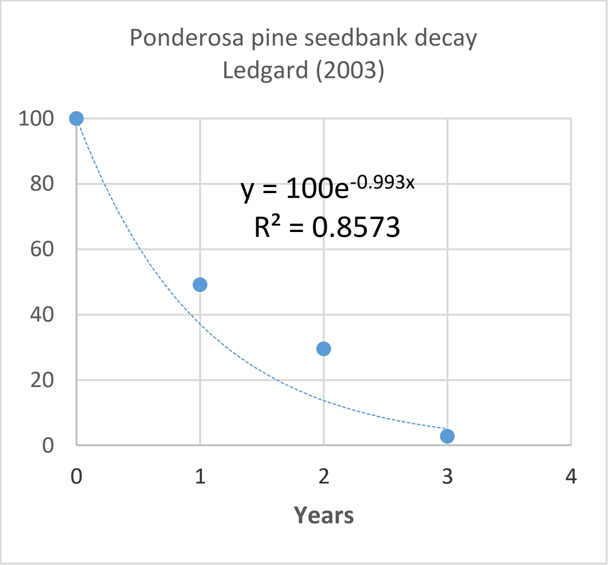


Pinus ponderosa **Ponderosa pine**

The model was fitted to *P. ponderosa* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003). The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model is shown in the graph.

The T_i values for 50, 20 10 and 5% survival are 0.7, 1.6, 2.3 and 3.0 years respectively.

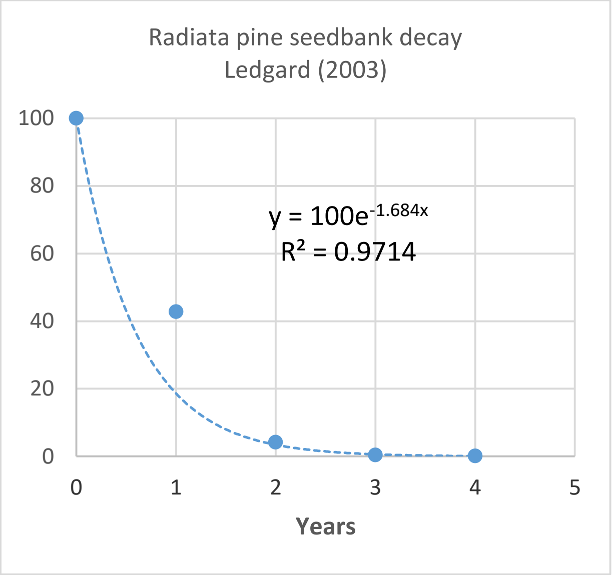


Pinus radiata **Radiata pine**

The model was fitted to *P. radiata* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003).The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model are shown in the graph.

The T_i values for 50, 20 10 and 5% survival are 0.4, 1.0, 1.4 and 1.8 years respectively.

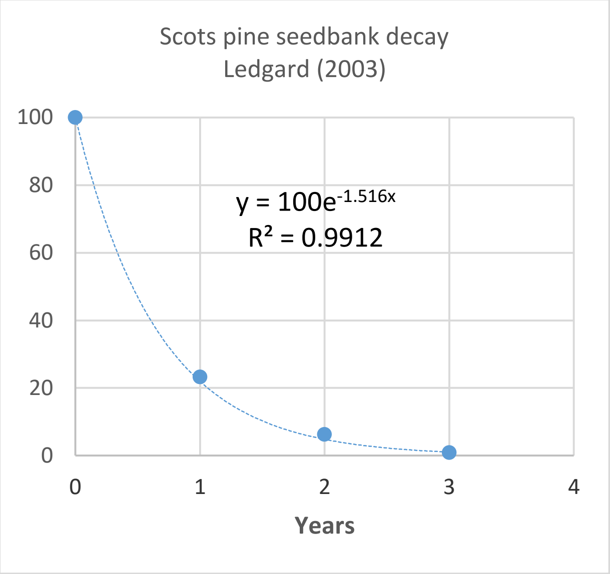


Pinus sylvestris **Scots pine**

The model was fitted to *P. slyvestris* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003).The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model are shown in the graph

The T_i values for 50, 20 10 and 5% survival are 0.5, 1.1, 1.5 and 2.0 years respectively.

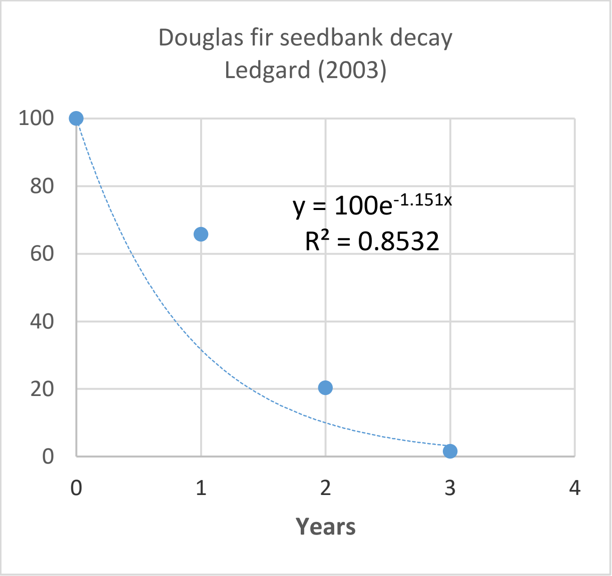


Pseudotsuga menziesii **Douglas fir**

The model was fitted to *P. menziesii* seed survival data derived from seedling emergence data from a study of six years duration in which a known number of seeds of the species were sown onto soils at four different locations in New Zealand (Ledgard, 2003). The model was fitted to the yearly averages, over the four sites, of seeds surviving.

The data and the fitted model are shown in the graph.

The T_i values for 50, 20 10 and 5% survival are 0.6, 1.4, 2.0 and 2.6 years respectively.

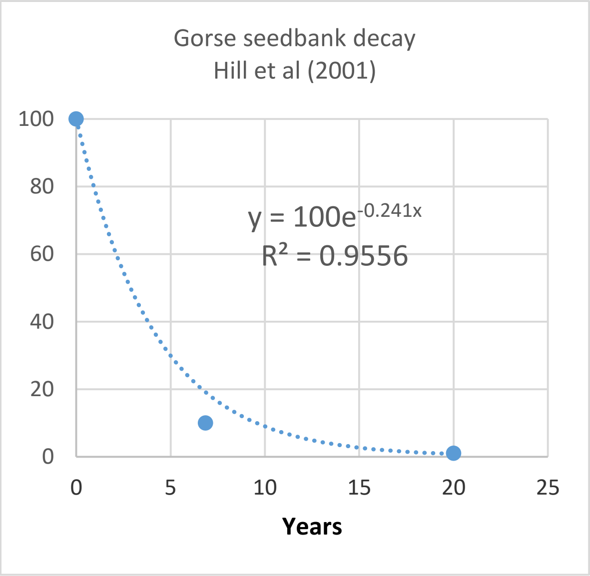


Ulex europaeus **Gorse**

The model was fitted using estimates of the number of years required for *U. europaeus* seeds buried at 50 mm to decline to 10% and 1% of the initial number determined in a comprehensive field experiment conducted in New Zealand (Hill *et al.*, 2001). The estimates (5.6-8.1 and 20 years respectively) were derived by the authors from data collected at three sites (Lincoln, Auckland, West Coast) where the seeds of the species had been buried at three different depths under pasture. The mean of the years-to-10% (6.85 years) was used, along with the 20 for years-to-1%, in fitting the exponential decay model.

The data and the fitted model are shown in the graph.

The T_i values for 50, 20 10 and 5% survival are 2.9, 6.7, 9.6 and 12.4 years respectively.



D5 Summary of the weed seed bank decay models

The times required (years) for the seed banks of the 16 weeds species to decay to 50, 20, 10 and 5% of their initial values, T_i, are summarised in the table below.

For the three tree species for which no seed survival data could be found, *Pinus mugo*, *P. muricata* and *P. pinaster*, their T_i values have been set equal to the mean of the 7 tree species for which data was available.

The T_{50} values can be thought of as "half-life" values for the seeds of the species in the soil seed bank.

Another useful summary metric from the models is the "% annual decline". This is given by $(1-e^{-r}) \times 100$. The values for each species are in the right-hand column of the table. Averages across species for each of the four species groups (herbs, shrubs, trees, grasses) are at the bottom of the table revealing marked differences in rates of decline between groups.

In only three of the thirteen cases was data from more than one experiment found. These were *Carduus nutans* (n=2), *Cytisus scoparius* (n=3) and *Nassella trichotoma* (n=2). In these three cases the seed bank decay estimates are given as the averages. The standard deviations for broom and nassella tussock indicate the wide variation in the estimates (*n*) making up these means. Although the two estimates for nodding thistle were very similar, it seems likely that if multiple sets of data existed for the other ten species, their seed bank decay rate estimates would also have been highly variable.

No data found for these three tree species - set equal to means of other trees		to decline to defined percentages of initial values in absence of seed input (*T*i)				% annual decline	*n*	SDEV % annual decline
Latin name	**Common name**	**50%**	**20%**	**10%**	**5%**			
Carduus nutans	Nodding thistle	4.0	9.2	13.2	17.2	16	2	0.1
Cytisus scoparius	Broom	4.9	11.4	16.3	21.2	33	3	26.8
Jacobaea vulgaris, syn Senecio jacobaea	Ragwort	3.3	7.7	11.0	14.3	19	1	
Larix decidua	European larch	0.5	1.2	1.7	2.3	73	1	
Nassella trichotoma	Nassella tussock	0.7	1.7	2.5	3.2	65	2	28.0
Pennisetum macrourum	African feather grass	0.1	0.3	0.4	0.5	100	1	
Pinus contorta	Lodgepole or contorta pine	0.7	1.5	2.2	2.8	65	1	
Pinus mugo	Dwarf mountain pine	*0.6*	*1.3*	*1.8*	*2.4*	*72*		
Pinus muricata	Bishop or muricata pine	*0.6*	*1.3*	*1.8*	*2.4*	*72*		
Pinus nigra	Corsican pine	0.5	1.2	1.7	2.2	75	1	
Pinus pinaster	Maritime pine	*0.6*	*1.3*	*1.8*	*2.4*	*72*		
Pinus ponderosa	Ponderosa pine	0.7	1.6	2.3	3.0	63	1	
Pinus radiata	Radiata pine	0.4	1.0	1.4	1.8	81	1	
Pinus sylvestris	Scots pine	0.5	1.1	1.5	2.0	78	1	
Pseudotsuga menziesii	Douglas fir	0.6	1.4	2.0	2.6	68	1	
Ulex europaeus	Gorse	2.9	6.7	9.6	12.4	21	1	
					Herbs	17		
					Shrubs	27		
					Trees	72		
					Grasses	83		

D6 Acknowledgements

I thank Karen Cousins, Knowledge Advisor, AgResearch, Invermay, for conducting the literature search required for this study.

D7 References

HARRADINE AR (1980) The biology of African feather grass (Pennisetum macrourum Trin.) in Tasmania. 1. Seedling establishment. *Weed Research* **20**, 165-169.

HILL RL, GOURLAY AH & BARKER RJ (2001) Survival of Ulex europaeus seeds in the soil at three sites in New Zealand. *New Zealand Journal of Botany* **39**, 235-244.

JAMES TK, RAHMAN A & TRIVEDI P (2010) Germination of seed from five broadleaf weeds after burial for up to 28 years in two soils. *New Zealand Plant Protection* **63**, 84-89.

JAMES TK, RAHMAN A, WARDLE DA & BONNER KI (1998) Survival of nodding thistle (Carduus nutans) seed buried at different depths in four soils. In Proceedings of the Fifty First New Zealand Plant Protection Conference, Quality Hotel, Hamilton, New Zealand,11-13 August, 1998., pp. 33-37.

LAMOUREAUX SL, BOURDÔT GW & SAVILLE DJ (2011) Population growth of *Nassella trichotoma* in grasslands in New Zealand slower today than in the past. *Acta Oecologica* **37**, 484-494.

LEDGARD NJ (2003) Wilding conifers - New Zealand history and research background. In Managing wliding conifers in New Zealand: present and future (RL HILL, *et al.*, eds.), Vol. 1, pp. 1-25. NZPPS, Chateau on the Park, Christchurch.

PAYNTER Q (2000) Factors affecting broom regeneration in Australia and their management implications. *Plant Protection Quarterly* **15**, 156-161.

REES M & PAYNTER Q (1997) Biological control of Scotch broom: modelling the determinants of abundance and the potential impact of introduced insect herbivores. *Journal of Applied Ecology* **34**, 1203-1221.

Appendix E Benefits

Table 4: Estimated Cross Margin by land use and by region for control of plant pests ($/ha/annum). Source Beef and Lamb NZ, DairyNZ, proprietary information.

	Dairy	Sheep and beef Intensive	Arable	Horticulture	Hill country	High country
Northland	$2,154	$564	$1,581	$9,100	$564	$57
Auckland	$2,154	$564	$1,581	$9,100	$564	$57
Waikato	$3,302	$564	$1,581	$9,100	$564	$57
Bay of Plenty	$3,549	$564	$1,581	$13,700	$564	$57
Gisborne	$3,549	$564	$1,581	$9,100	$407	$57
Hawke's Bay	$3,241	$564	$1,581	$13,700	$407	$57
Taranaki	$3,430	$564	$1,581	$9,100	$564	$57
Wellington	$3,241	$564	$1,581	$13,700	$407	$57
Manawatu-Wanganui	$3,241	$564	$1,581	$13,700	$407	$57
Nelson	$2,154	$564	$1,581	$13,700	$221	$57
Tasman	$2,154	$564	$1,581	$13,700	$221	$57
Marlborough	$4,489	$564	$1,581	$13,700	$221	$57
Canterbury	$4,489	$564	$1,581	$9,100	$221	$57
West Coast	$2,154	$564	$1,581	$9,100	$221	$57
Otago	$3,452	$904	$1,581	$9,100	$221	$57
Southland	$3,452	$904	$1,581	$9,100	$221	$57

Table 5: Estimated benefits from control of animal pests by proneness type ($/ha/annum).

	Low	Moderate	High	Extreme
Rabbits	$0.00	$93.46	$56.07	$4.67
Possums	$0.00	$2.73	$7.39	$12.04

Source: Rabbits – ECan, (Harris, 2016), Possums various (Cowan, 2009; Greer, 2006) updated for CPI changes.

Appendix F Inspection costs

Inspection costs have been sourced from regional councils. Where data is not available, the average of other councils is used.