The economic impact of failures in plant protection to New Zealand

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Abstract

Plant weeds, pests and diseases comprise significant threats to pastoral agriculture in New Zealand. The extent of damage incurred by New Zealand's agricultural industry from these weed and pest threats varies significantly depending on the response implemented, and the technologies available. This paper assesses the projected economic impact of three individual potential failures in plant protection, specifically the spread of clover root weevil, giant buttercup and glassy-winged sharpshooter across New Zealand, and the potential mitigation of economic loss caused by these failures through various response methods. This assessment is carried out with the use of a national-level agricultural production and value model, based on data from the Ministry for Primary Industries farm models and the Lincoln Trade and Environment Model, an international trade and environment model. The model projects economic impact on agriculture until 2030, comparing the differences in economic impact between business as usual without the advent of each threat and then with the advent of each threat alongside various potential responses. The modelled responses cover firstly the most probable responses, and secondly the use of biological control agents, in the form of a parasitoid or bio-herbicide control. The results show that biological controls offer the most effective and feasible responses to the modelled threats to pastoral agriculture compared with other responses.

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Introduction

New Zealand is particularly vulnerable to the impact of weeds, pests and diseases (Goldson et al., 1997) and, significantly, it has been estimated that over 90% of this country's invertebrate pests are alien invasive species (Barlow and Goldson, 2002). Despite this, the severity of pest impacts is often overlooked as a source of economic loss and environmental degradation because the impacts of pest damage are frequently being attributed to other causes such as poor seed strike. This misattribution can occur for a variety of reasons, including the often cryptic or camouflaged appearance of pest species, concealed feeding sites (e.g. root-feeding or stem-mining habits) and ambiguous damage symptoms. The latter particularly applies to pathogens which can produce very non-specific symptoms. Unsurprisingly, therefore, and in an attempt to correct such misapprehension over recent years, quite a number of contributions have been made by bioprotection researchers themselves to produce monetary estimates of damage. In particular, this has pertained to analyses into pasture/forage pests (Prestidge Barker & Pottinger,1991; Goldson, Proffitt & Muscroft-Taylor, 1993; Barlow and Goldson, 2002; Goldson, Rowarth & Caradus, 2005) and weeds (Bourdôt et al., 2012; 2013). However, this has also generally applied to the land-based industries (Suckling and Popay, 1993). Particularly spectacular estimates have been made of the financial impacts of pasture damage. This is simply because 50% of the land area of New Zealand is pasture and the multipliers are therefore very high. As a result, such estimates have been met with scepticism often because they have been generated without the imprimatur of well recognised economists and therefore have apparently not always been accepted. A notable exception to this was the work of Bertram (1999). Partly in response to such circumstances this contribution seeks to confirm via standard econometric methods earlier economic estimates of impacts based on a pasture pest, a pasture weed and an estimate of the likely impact of a potential pest species of grapes.

Primary industries are of high importance to New Zealand, in particular the agricultural sector, contributing $9.4 billion to GDP, or 6.4% of total GDP in 2012 (Statistics NZ 2013). One of the most significant threats to New Zealand's agriculture is the occurrence of failures in plant protection; these can be pests, weeds or plant diseases becoming more important or developing from new invasions. One recent example of a failure in plant protection is the PSA outbreak on kiwifruit, which has been estimated to cost between $310 and $410 million to New Zealand agriculture, over 5 years (Greer & Saunders, 2012).

This project demonstrates the economic cost to agriculture in New Zealand of the spread of various biological pests, weeds and diseases. To estimate this, a model has been developed to map these economic impacts and the economic value of different mitigation and biocontrol responses to challenges, thus showing value of having strong bioprotection science to anticipate, meet and mitigate these challenges and threats.

This paper focuses solely on the effects of challenges to New Zealand's pastoral industries, other impacts on New Zealand's biodiversity profile, or potential and flow-on effects to other industries have not been accounted for.

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Methodology

Three scenarios of damaging pests and weeds in New Zealand agriculture were modelled; these represent a range of current and potential challenges to agriculture in New Zealand. The selected scenarios are detailed in Table 1.

Table 1: Scenario descriptions

Scenario		Responses	
#	Name	First	Second
1	Clover root weevil	Increased N use	Parasitoid biological control
2	Giant buttercup	Increased herbicide	Bio-herbicide
3	Glassy-winged sharpshooter	Replanting vines	Bio-herbicide

Each scenario models the outcome from a lack of plant protection for a particular farm type in New Zealand, and presents up to three different approaches for mitigating the negative effects on production. As presented, the mitigation approaches are informed by the literature surrounding each case and personal communication with scientists in the relevant fields, thus describing the most useful responses available or potentially available within the modelling timeframe. The mitigation responses cover approaches such as the use of biological controls for pests or weeds, changes in farm systems and farm inputs and/or the use of specific pesticides or herbicides. In each of these cases the cost of implementation and the beneficial effect of the implementation are accounted for.

Quantifying the incidences and spread of a pest or weed, and the probable mitigation responses was achieved by taking the data and projections from the literature and personal communication with plant protection specialists where available. Some scenarios, however, also encompass potential responses to these challenges that are outside New Zealand's experience, for example a scenario deals with an incursion of a pest until now unknown to New Zealand agriculture, or mitigation technologies that are still in the preliminary stages of development or have yet to be released for wide-scale application. In these cases, estimates were derived from case-studies of foreign incursions and with the guidance of specialists.

Model

An economic impact assessment model was developed to quantify the effects of these challenges to plant protection. The model uses both data from the Lincoln Trade and Environment Model (LTEM) and the Ministry for Primary Industries (MPI) farm monitoring reports. The LTEM component gives national level projections derived from trading conditions for production and price figures for agricultural commodities up to 2020. These projections are then disaggregated to the farm level and normalised to the budgets for MPI's model farms as of the 2011 farm monitoring reports (Ministry of Agriculture and Forestry:

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MAF, 2011a; MAF, 2011b; MAF 2011c; MAF 2011d). The approach allows for both the projections and international trade effects of the LTEM's national focus to be applied to farm level profits, taken from MPI. The model currently projects to 2030, using linear extrapolations of the projection given by the LTEM.

The effects of pests and weeds, and the recovery scenarios can be modelled as changes to either total production, price, total or per hectare income, total or per hectare cost or stocking rates. These changes can be applied to any year within the model's operating timeframe, or gradually over a designated time period.

The model gives outputs in profitability by commodity and scenario at an aggregate national level, using a discount rate of 8%. Also presented are the losses for each scenario compared to the baseline, and the benefits of the recovery scenarios compared to the initial loss scenario. These results are given for both the entire period of modelling and per hectare per year.

Scenario 1

Clover Root Weevil

The clover root weevil (*Sitona lepidus*) is a pasture pest native to Europe which was discovered in New Zealand in 1996 (Gerard et al., 2007a), and by 2005 was present in pastures across the North Island (Gerard et al., 2009). Currently the weevil is spreading through the South Island.

All stages of the weevil affect white clover and this has two impacts on pastures. First is the loss of dry matter through the depletion of clover due to feeding. Second is the loss in nitrogen fixation also due to rhizobial root nodule damage.

In most assessments of the effects of this weevil, estimates of the loss to pasture have been based on records of damage found on Waikato dairy farms. In such farms, the weevil causes up to 35% reductions in total dry matter and up to 83% less nitrogen fixed as a result of clover loss (Gerard, Hackell & Bell, 2007a). These effects would be less severe nationally due to lower clover content of pastures in other regions. Because of this, a 10% reduction in the production of milk solids, beef and sheep, has been used for this report. This is the same approach that was used in the medium impact scenario from the New Zealand Institute of Economic Research (NZIER)'s earlier assessment of the impacts of the clover root weevil (Wear & Andrews, 2005).

The weevil is thought to spread at a rate of 35 km/year on average (Willoughby & Addison, 1997). Applying this to the map of current weevil distribution throughout the South Island developed by AgResearch (Figure 1) we can assume that all of New Zealand pasture will be affected by the weevil by 2014 and equilibrium populations of the weevil will be fully established by 2015.

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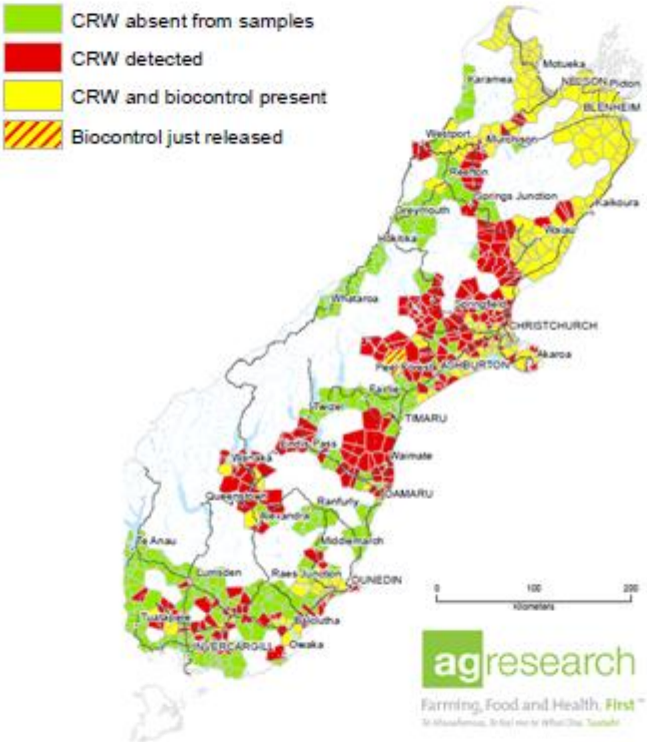
Figure 1: Current South Island distribution of CRW & its biological control agent.



Source: Phillips et al., 2013.

Response scenarios

For the impact of the clover root weevil on New Zealand agriculture, two mitigation responses are modelled. The first is an increase in the use of nitrogen fertiliser the second is spread of a weevil parasitoid as a biological control agent.

Response 1: Increased use of nitrogen

One current response to the damage incurred by the spread of the weevil is the use extra nitrogen fertiliser to offset the reduced nitrogen fixation resulting from clover damage, and the loss in consumable dry matter on pasture. The assumptions and data informing this mitigation scenario were taken from the NZIER's report on the economic impact of clover root weevil (Wear & Andrews, 2005) and the 2010 Lincoln Financial Budget Manual (Pangborn, 2010). It is assumed that clover naturally releases 200 kg nitrogen/year/hectare, and that clover root weevil prevents nitrogen fixation in 50% of the nodules. Therefore, 100 kg of nitrogen must be replaced via fertiliser to maintain pasture production at normal levels. The costs associated with such extra application of nitrogen fertiliser are detailed in Table 2.

Table 2: Cost for replacing nitrogen (N) lost due to clover root weevil nodule damage

N deficiency	100 Kg/ha/yr
Urea (46% N) required	217.39 Kg/ha/yr
Price of Urea (FBM)	$620/t
Application Cost @ $48.20/ha (FBM)	$10.48/ha
Cartage Cost for 30km @ $16/t (FBM)	$3.48/ha
Total Cost	$148.74/ha

FBM: Farm Budget Manual (Pangborn 2010)

The use of extra nitrogen to mitigate the effects of clover root weevil has been shown to increase total pasture production, but cause a slight decrease in total metabolisable energy (White & Gerard, 2006). This was found to be due to a reduction in clover content of the pasture from weevil activity, but an increase in total ryegrass due to the application of nitrogen. For the purposes of modelling we have assumed this to equate to pre-weevil production levels, occurring as a lagged response, one year after the full establishment of the weevil.

This response is sensitive to the cost of nitrogen fertiliser and the capability of land to bear additional nutrient load. This scenario does not take into account the negative groundwater effects, which using extra nitrogen fertiliser on a national level would incur. Tait and Cullen (2006) estimate the external costs of dairy farming in Canterbury to surface and groundwater, air, biodiversity and human health at $28.7 to $45 million per annum. Of this amount, $155,000 per annum is the specific impact on surface and groundwater, which would be affected by increased nitrogen use on farm. Greenhouse gas emissions per hectare would also increase with additional fertiliser use. Calculating the impacts from the increase of nitrogen fertiliser applied in this scenario would require additional resources beyond the scope of this project.

Furthermore, current discussion around the environmental impacts of agricultural use of nitrogen, suggest that limits to the use of nitrogen on farm may be implemented in the near future by regional councils. Such limits would make this scenario an unfeasible option for response to the incursion of the clover root weevil.

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Response 2 & 3: Biological control

The second modelled response to the impacts of clover root weevil is based on the use of a biological control agent, the wasp *Microctonus aethiopoides* (Irish strain), which is a parasitoid of the weevil (Goldson, Rowarth & Caradus, 2005; McNeill et al., 2006). The wasp usually lays one egg into each adult weevil, rendering the female infertile and killing it upon the emergence of the fifth instar larva. The wasp was released in 2006 and has since been established in most New Zealand regions, spreading at about 15km a year which is 20km/year slower than its host.

For the modelling exercise the biological control is presumed to have been introduced at the start of the modelling timeframe, and established nationwide in 2018, 3 years later than the weevil. Once established and accommodating any associated density-dependent processes, the Irish wasp is assumed to lead to yields of up to 80% of the original potential production. As the level of control given by the Irish wasp varies, two scenarios have been modelled: the first, a lower estimate of 60% of original yields, the second an upper estimate of 80% of the original pasture yield.

This biological control is modelled as having no additional cost to farmers.

Results

Figure 2 illustrates the outputs of the model for the clover root weevil impact scenarios. The base scenario shows the business-as-usual projections from the LTEM for New Zealand's pastoral sector without any impact from clover root weevil. The initial scenario shows these projections with the damage caused by the incursion and eventual establishment of the clover root weevil in New Zealand pastures. Three recovery scenarios are shown in Figure 2: additional N use (+ N use) shows the effect of extra nitrogen fertiliser to compensate for the decrease in clover N fixation and total dry matter, and biological control 60% and 80% show the establishment of the parasitoid biological control giving yields at 60% and 80% of clover root weevil, respectively.

Figure 2: Clover root weevil's impact on New Zealand pastoral profits until 2030

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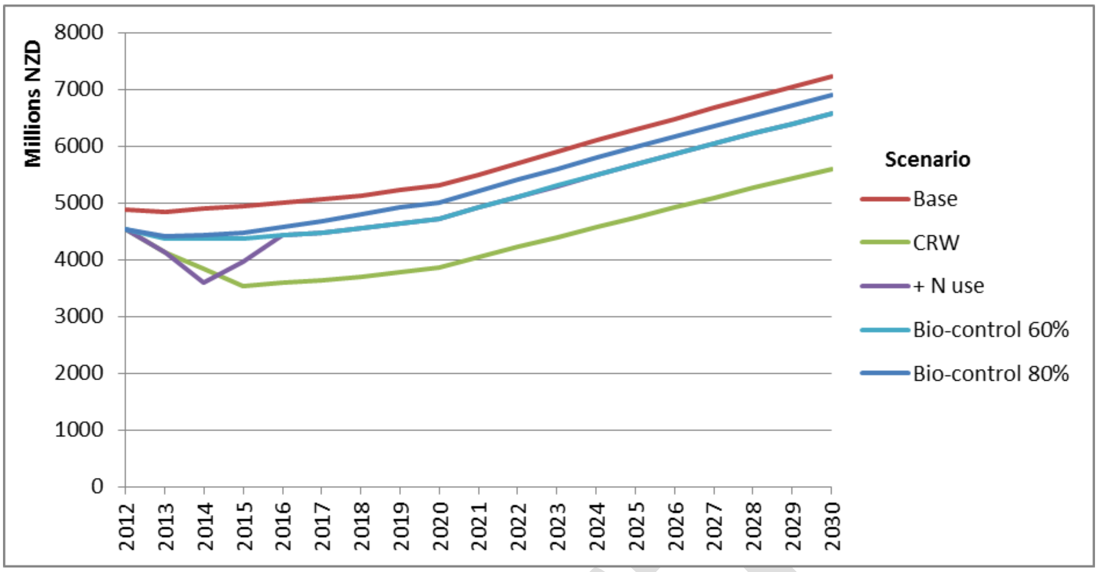

Table 3 shows the total loss from the incursion of clover root weevil within the timeframe of the modelling exercise at over $11 billion. Nitrogen replacement or the first recovery scenario would mitigate over $5 billion worth of losses, whilst the full establishment of the parasitoid biological control at by 2018 would mitigate over $6 billion NZD at 60% parasitism. At the 80% figure this amounts to the parasitoid biological control being worth $400-$500 million per year.

Table 3: Total change in pastoral profits 2012-2030, for a range of clover root weevil scenarios

	Total (milNZD)	Mitigation (milNZD)
Clover root weevil	-11,467	-
Additional N use	-6,156	5,311
Biological control 60%	-5,054	6,413
Biological control 80%	-3,278	8,189

Figure 3 shows the total losses incurred by clover root weevil against the mitigation resulting from the three response scenarios. The 80% biological control has the greatest mitigation, whereas the additional use of nitrogen and the 60% biological control give roughly the same mitigation rate by 2030.

Figure 3: Total loss and mitigation in pastoral profits 2012-2030, for clover root weevil scenarios

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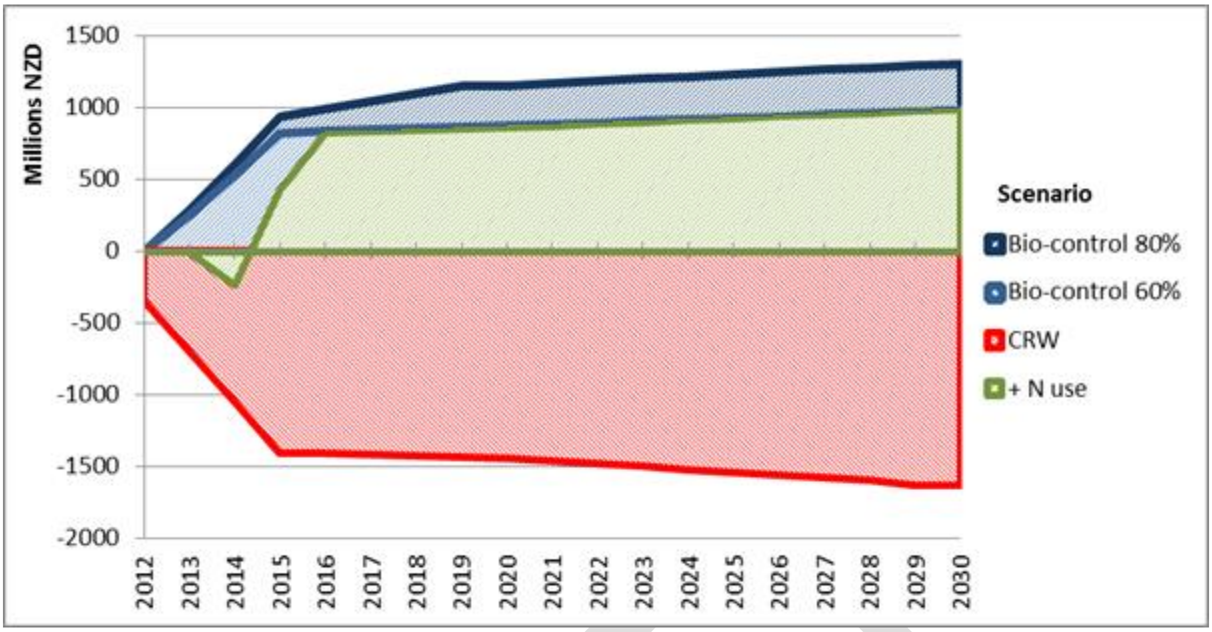

Table 4: Total change in pastoral profits annuitized, for clover root weevil scenarios

	Total (milNZD)	Mitigation (milNZD)
Clover root weevil	-604	-
Additional N use	-324	280
Biological control 60%	-266	338
Biological control 80%	-173	431

In order to further break down and illustrate these results Table 4 presents the profits for each scenario annually, and Table 5 shows the annuitized profits by hectare. Clover root weevil is then expected to reduce pastoral profits on average by $81 per hectare, where additional N could mitigate about half of this, and the biological control between 55% and 72%.

Table 5: Total change in pastoral profits annuitized per ha, for clover root weevil scenarios

	Total (NZD)	Mitigation (NZD)
Clover root weevil	-81.36	-
Additional N use	-43.68	37.68

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Biological control 60%	-35.86	45.50
Biological control 80%	-23.26	58.10

Scenario 2

Giant Buttercup

Giant buttercup (*Ranunculus acris*) is a weed currently present in pastures in six of the 16 dairying regions of New Zealand. The weed is unpalatable to ruminants and thus causes a drop in the metabolisable content of pasture land as cattle avoid the weed and pasture surrounding it. In this way the giant buttercup is thought to cost the New Zealand dairy industry $156 million per year (Bourdôt & Saville, 2010). The weed is expected to eventually spread throughout New Zealand pasturelands, albeit slowly. The following scenarios assume the weed will have spread across New Zealand by 2027.

Giant buttercup also occurs on sheep and beef land; however, here it does not become a problem weed “usually persisting as stunted plants that fail to reach above the pasture canopy” (Bourdôt & Lamoureaux, 2002). Thus, giant buttercup is modelled as only affecting dairy pastures.

A study on the economic impacts of giant buttercup (Bourdôt 2003) uses 33.24% as an estimate of loss of usable dry matter. The loss in production from giant buttercup nationwide is based on this estimate in the modelled scenarios.

Response 1: Extra herbicide use

The first modelled response to the spread of giant buttercup is based on the use of a flumetsulam herbicide. This herbicide is currently one of the most effective agents for controlling giant buttercup. Prior to this the phenoxy herbicide 2-methyl-4-chlorophenoxyacetic acid (MCPA) had been used to control the weed; however, this chemical has been losing its effectiveness, thereby requiring continously increasing rates of application as resistance has increased. Bourdôt & Lamoureaux (2002) noted that MCPA treatment would need to be withheld from a resistant population for 28 years prior to a return of level of buttercup susceptibility that would give effective control.

Harris & Husband (1997) showed that annual repeat application of flumetsulam at label rates of 50g/ha over consecutive years provided 80% control of giant buttercups after 4 years. These figures have been adopted in the model used in this contribution, along with per hectare application costs as detailed in Table 6, using current label rates for giant buttercup control of 65g/ha with a flumetsulam herbicide. This is an underestimate of cost as, over time, resistance is likely to occur requiring application rates of the herbicide exceeding label rates, thus increasing total cost.

Table 6: Per hectare (ha) cost of applying flumetsulam

Flumetsulam (Preside) required	65g/ha
Spraying Oil (Uptake) required	1L/ha
Cost of Flumetsulam (Preside) & Spraying Oil	$44.85/ha
Average ground application cost	$26/ha
Total Cost	$70.85/ha

Response 2: Biological control

One potential alternative response to the spread of giant buttercup is the application of a naturally-occuring fungus, *Sclerotinia sclerotiorum*, which can infect and kill buttercups.

The fungus has been found to cause 75% plant mortality rates in controlled studies, and 50% and 57% plant mortality in dairy pastures (Cornwallis et al., 1999; Green et al., 1993 Harvey & Bourdôt, 2001). Pasture plants are thought to be more resistant to infection, being older and larger than their counterparts in controlled environments. Currently, methods are being explored to increase the mortality rate in pastures. For this modelling exercise, a 50% mortality rate of the giant buttercup from the application of *S. sclerotiorum* has been adopted. Under this assumption it can be estimated that if the fungal biological control agent is applied in the field for six years, the giant buttercup would thereafter have a minimal effect on production.

For modelling purposes it is assumed that the *S. sclerotiorum*-based bio-pesticide has been developed to the extent that it is useful for commercial application (estimated requirement time is 3 years). The estimated cost of this biological control has been placed at $300 per hectare (G. Bourdôt pers. comm, 2013). The costs of applying the biocontrol *S. sclerotiorum* are estimated to be $26 per hectare, the same as the ground application of flumetsulam. Due to the high modelled cost of this biological control option, it is only considered applicable to use on dairy land as the profit margins for sheep and beef farming are not sufficient for this product to be economic at $326 per hectare.

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Results

Figures 4 & 5, and Table 7 show that the spread of giant buttercup could cost New Zealand upwards of $18.8 billion over 18 years. The use of extra herbicides on affected pastures would mitigate almost 60% of these losses, and the use of the fungus *Sclerotinia sclerotiorum* as a bio-herbicide would mitigate almost 70%.

Figure 4: The impact of giant buttercup on New Zealand dairy profits until 2030

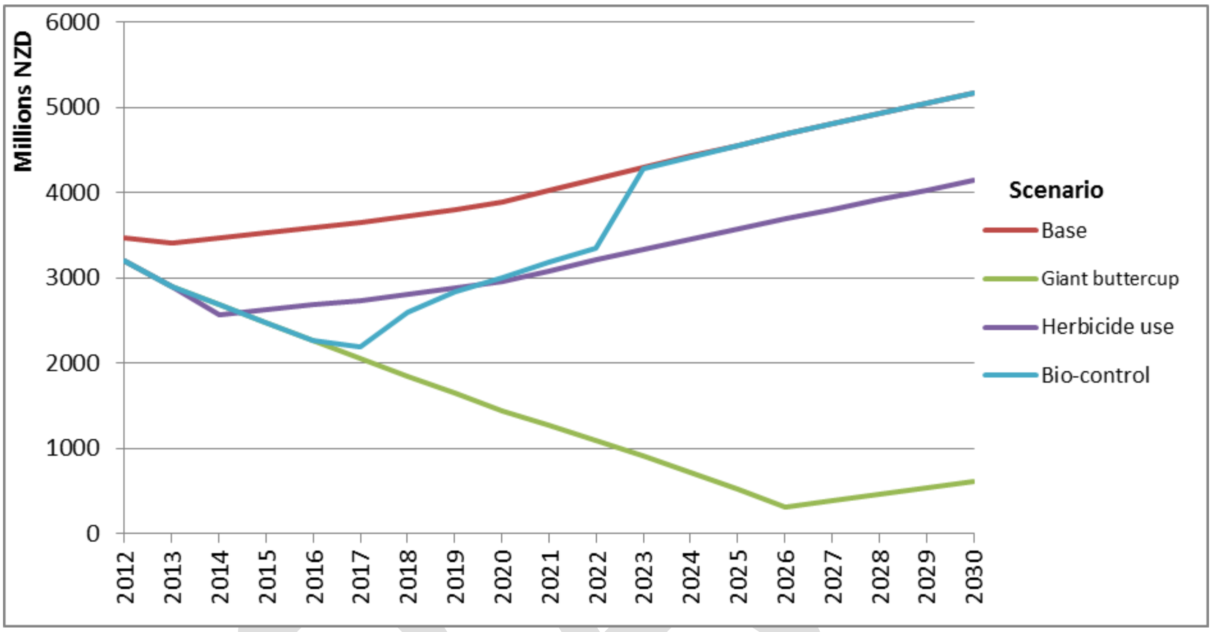

Table 7: Total change in dairy profits 2012-2030, for the Giant buttercup scenarios

	Total (milNZD)	**Mitigation (milNZD)**
Giant buttercup	-18,810	-
Herbicide use	-7,621	11,189
Biological control	-6,042	12,767

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Figure 5: Total loss and mitigation in dairy profits 2012-2030, for the giant buttercup scenarios

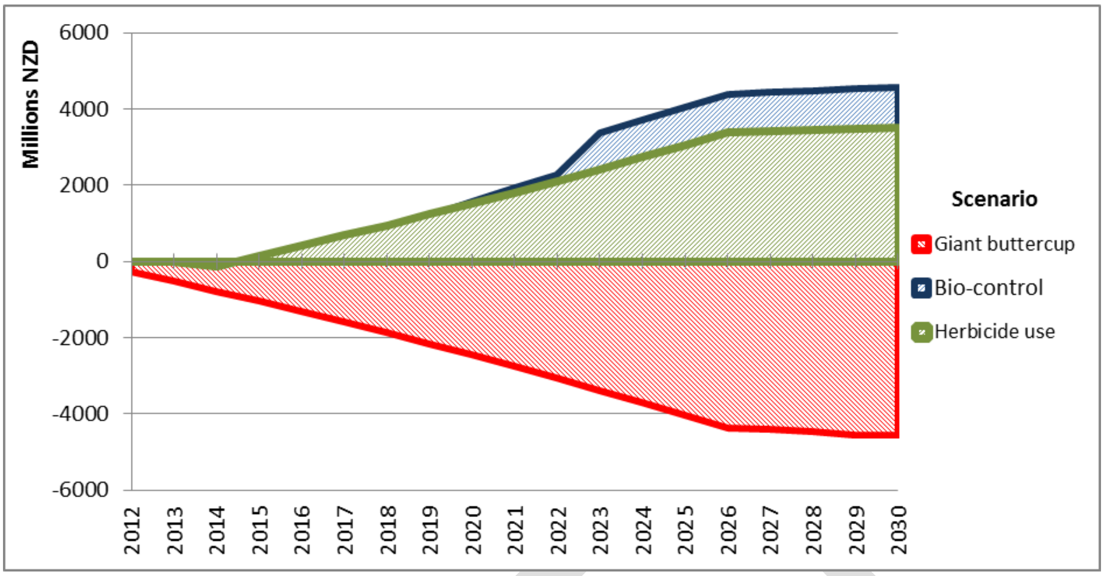

Table 8 shows the total changes in each scenario averaged across the effected period. Giant buttercup causes a loss to dairy of almost a billion dollars a year.

Table 8: Total change in dairy profits annuitized, for the giant buttercup scenarios

	Total (milNZD)	Mitigation (milNZD)
Giant buttercup	-990	-
Herbicide use	-401	589
Biological control	-318	672

Per hectare, shown in Table 9, the spread of giant buttercup would cost over $640, this would be reduced to approximately $245 with the use of flumetsulam, finally with the bio-herbicide, it would cost $194, mitigating $410 per hectare.

Table 9: Total change in dairy profits annuitized per hectare (ha), for the giant buttercup scenarios

	Total (NZD)	Mitigation (NZD)
Giant buttercup	-604.18	-
Herbicide use	-244.80	359.39
Biological control	-194.08	410.10

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Scenario 3

Glassy-winged sharpshooter

The glassy-winged sharpshooter (GWSS), *Homalodisca vitripennis*, is a leafhopper insect native to Mexico, which can cause widespread damage to citrus trees, grape vines and arable crops through feeding and the spread of Pierce's disease (PD).

PD affects grape vines by blocking the plant's xylem leading to vine death within one to five years. PD is caused by a strain of the bacterium *Xylella fastidos*, and there is no known cure for the disease or the direct prevention of it.

While the GWSS causes damage to citrus trees through water loss associated with feeding, its main potential threat to the New Zealand agricultural industry is in its capibility to spread the bacterium that causes PD. This disease already exists in New Zealand, but there are currently no New Zealand vectors of the disease capable of tranferring the disease to grape vines.

When the GWSS feeds on an infected plant, the disease-causing bacteria can attach to the sharpshooter's mouth and colonise its gut, thereby providing a reservoir for the bacteria to be transferred to other plants.

The GWSS spread to California in the late 1980s and from there has spread to French Polynesia in 1999, Hawaii in 2004 and the Cook Islands in 2007, showing the sharpshooter's ability to be spread through air travel, and move closer to New Zealand.

In California, the incursion of GWSS and the spread of PD is estimated to cost the Californian wine industry 110 million USD each year (Alston et al., 2012), $59 million of this is from the loss of productivity in grape growth, the remaining $51 million is spent on preventative measures and funding the Pierce's Disease Control Program.

The modelled scenario of the spread of GWSS to New Zealand focuses only on the impact on grape growers, although there is evidence that an incursion would also impact on citrus growers, and native trees and shrubs.

The whole of New Zealand is thought to be climatically suitable for GWSS; however, PD is only severe in the United States where the average minimum January temperature is greater than 4.5°C, thus it is only a threat to North Island grape growers.

It is assumed that the spread of GWSS in New Zealand would be similar to its spread over California. Maps showing the prevalence of the GWSS in California from the Californian Department of Food and Agriculture show that it has spread approximatelly 600 miles over seven years, from this GWSS was modelled to be fully established across the North Island eight years after its first incursion. Following the establishment of the GWSS, grape yield's are modelled as declining to zero over four years due to vine death associated with PD.

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Response 1: Replanting vines

The first response scenario for the incursion of GWSS and PD is to uproot the vines and replant. This option is extremely costly, incurring both the cost of replanting all affected vines, but also the loss of revenue from a cessation of production as the new vines mature.

In modelling, the new vines are assumed to take four years to mature. The capital costs of replanting per hectare, shown in Table 10, are spread over 30 years.

Table 10:Replanting cost/hectare

Cost of plant material	$16,566
Cost of vine guards	$3,012
Pulling old vines	$8,031
Planting vines	$5,722
Replanting	$331
Training for 3 years	$1,807
Total	$35,469
Lost grape income for 3 years	$45,000
Total	$80,469
Lost wine income for 3 years	$195,840
Total	$276,309

Source: G. Creasy, pers. comm., 10 Sep 2013

The replanting of affected vines restores productivity; however, it does not grant any increased resistance against future incursions of GWSS. Future infections of the new vines are possible. This modelled response only simulates single replants with no second incursions within the shown period.

Response 2: Biological control

The second response scenario for the GWSS scenario is the establishment of a parasitoid of GWSS. Many species of parasitic wasps have been considered and used for the control of the GWSS in California. For this model, we focus on *Gonatocerus ashmeadi*, which has been used effectively in controlling the GWSS in Tahiti. *G. ashmeadi* is thought to have no negative effects on other New Zealand insect fauna (Biosecurity New Zealand), and thus could be introduced promptly following an outbreak of GWSS.

G. ashmeadi has reduced populations of GWSS in Tahiti by over 90% one year after release, and up to 95% on eight islands across French Polynesia (Grandgirard et al., 2008).

It has been argued that the colder climate of New Zealand will be less suitable for the establishment of *G. ashmeadi* (Charles & Logan, 2013), suggesting that the parasitoid may be less effective across the whole of New Zealand than it has been in California and the Pacific. In the warmer regions of the North Island the wasp should still be effective, although slower to respond to increases in populations of GWSS. As the model's aim is only at assessing the impacts of the spread of PD on North Island vineyards, which are predominantly located in

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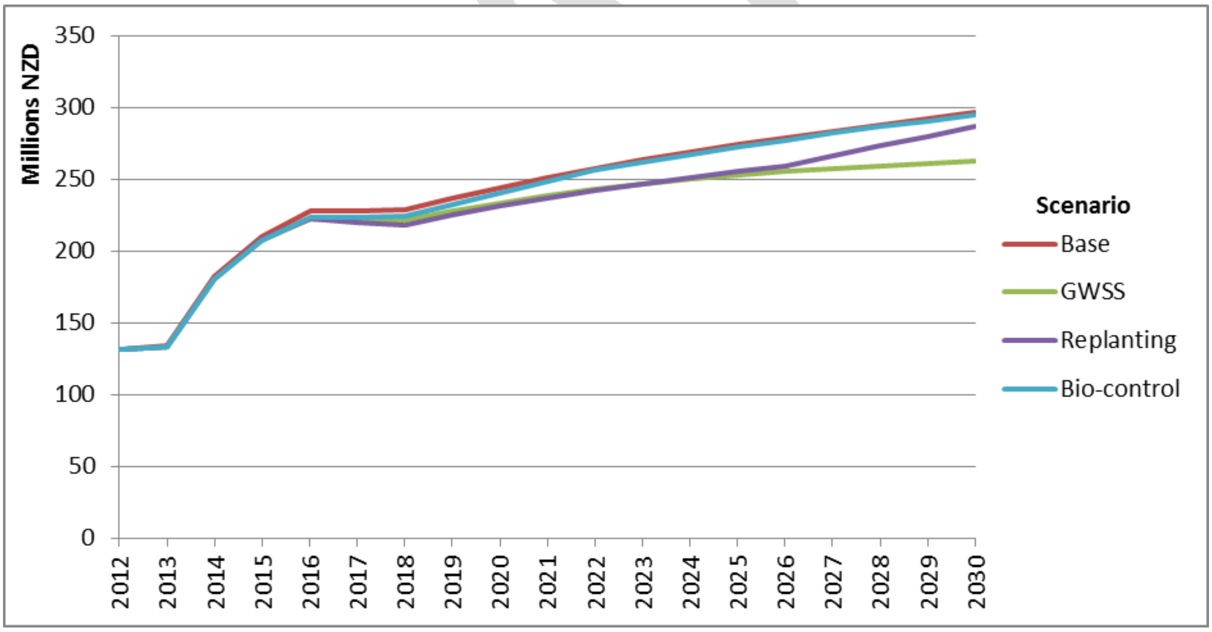
the warmer regions, we have assumed the wasp to be effective in areas with the GWSS. Given the success of *G. ashmeadi* in French Polynesia (Grandgirard et al., 2008) a conservative estimate of a 85% reduction in the populations of GWSS has been made. It is also presumed that the GWSS would take eight years to become established across the North Island.

There have been no extra costs assumed for the establishment of *G. ashmeadi*, although it is recognised that this would incur costs via the New Zealand Environmental Protection Authority.

Results

The majority of New Zealand's viticulture profits come from vineyards in the South Island, thus whilst the GWSS is expected to cause great losses in North Island vineyards, it would have a relatively small effect on New Zealand's grape industry as a whole, as shown in Figure 6.

Figure 6: The impact of the glassy-winged sharpshooter on New Zealand's viticulture profits until 2030



The effects on North Island growers is shown in Figures 7 & 8, and Table 11. The GWSS creates a steady decline in the profitablity of viticulture over the modelled period. Replanting creates a sharp decline, losing profitability swiftly as infected vines are uprooted, followed by a long plateau as the sharpshooter spreads causing additional vineyards to replant their vines. This period ends in 2026 where sufficient new vines have matured to compensate for areas still undergoing replanting. From this point the industry quickly recovers, although it will not reach base levels due to the continued incurred capital costs of replanting.

Figure 7: The impact of the glassy-winged sharpshooter on North Island viticulture profits until 2030

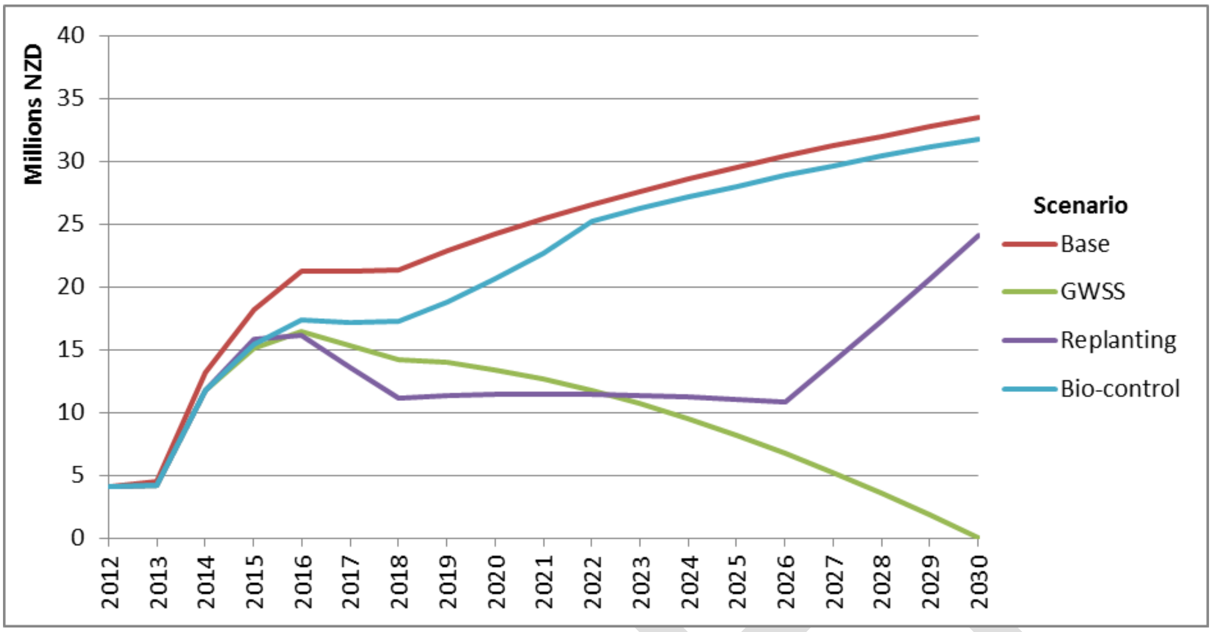


Table 11: Total change in viticulture profits 2012-2030, for the glassy-winged sharpshooter scenarios

	Total (milNZD)	**Mitigation (milNZD)**
Glassy-winged sharpshooter	-88.72	-
Replanting	-76.65	12.07
Biological control	-19.45	69.27

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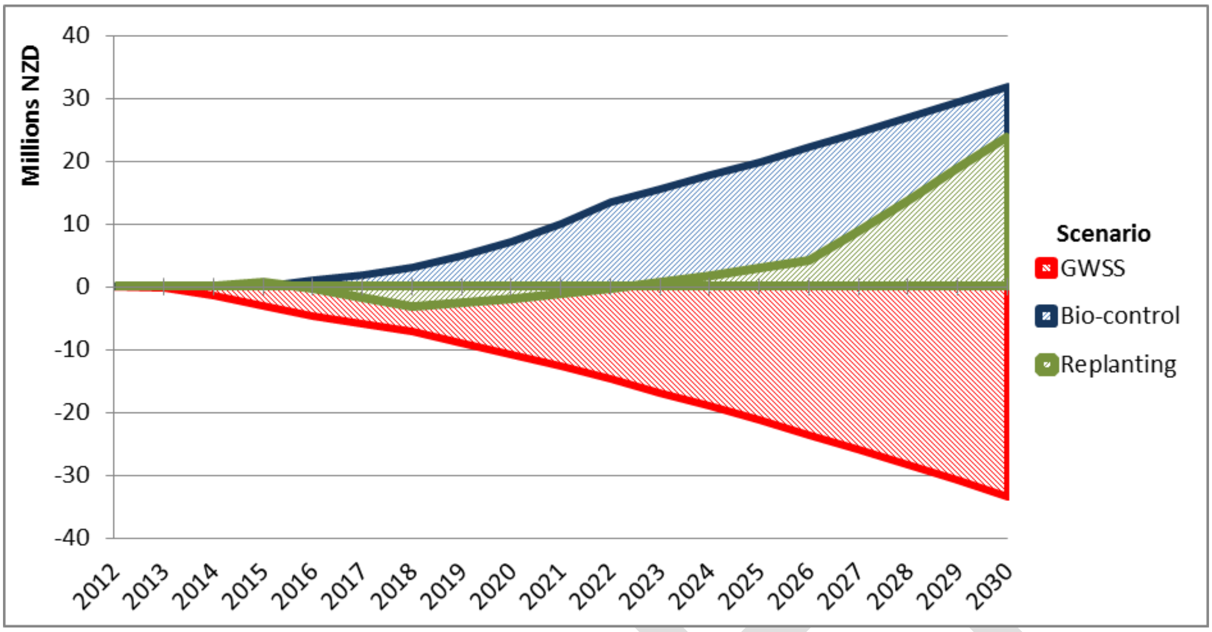
Figure 8: Total loss and mitigation in viticulture profits 2012-2030, for the glassy-winged sharpshooter scenarios



The first response modelled for the advent of the GWSS was replanting affected vineyards. This is found to be ineffective for mitigation in the modelled period. Two additional considerations should be made regarding this response. First, is that over a longer period of modelling it would eventually be a profitable option if vineyards can remain in operation without production for the four years needed for new vines to mature. Second, there is no guarantee that secondary incursions of the GWSS and PD could not occur. With this in mind this recovery option is higly unsatisfactory, with high capital costs, risk of future infection and a four-year regrowth period without production for affected vineyards.

Table 12 shows the change in profits annuitized over the modelled period, here glassy-winged sharpshooter causes losses of almost 4 million NZD per hectare.The biological control response, *G. ashmeadi*, given the assumed rates of parasitism, mitigates over 85% of these losses.

Table 12: Total change in viticulture profits annuitized, for the glassy-winged sharpshooter scenarios

	Total (milNZD)	Mitigation (milNZD)
Glassy-winged sharpshooter	-4.93	-
Replanting	-4.26	0.67
Biological control	-1.08	3.85

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Table 13 shows the change in annuitized viticulture profits by hectare. The GWSS on average costs North Island viticulture $620.08 per hectare. Replanting vineyards over the modelled period mitigates on average almost $95 per hectare, although with future costs incurred. The biological control is most effective mitigation response over the modelled period, saving almost $550 per hectare per year in otherwise sustained losses.

Table 13: Total change in viticulture profits annuitized per hectare, for the glassy-winged sharpshooter scenarios

	Total (NZD)	Mitigation (NZD)
Glassy-winged sharpshooter	-620.08	-
Replanting	-535.72	84.37
Biological control	-135.95	484.13

Conclusions

Biological control is a pivotal component of modern, science-led bioprotection. The broader literature suggests biological control of pests, weeds and plant diseases can be elegant, persistent, non-polluting and inexpensive, as well as conferring on businesses distinct marketing advantages. In fact, the benefit:cost ratios of many biological control successes have exceeded 300:1 (Gurr et al., 2012; Wratten et al., 2013). The analysis presented here takes a well-established New Zealand pest, a weed of which the importance is increasing and a serious insect pest that has reached the Pacific Islands and is expected here imminently. The analysis examines management options for these organisms, including biological control. Using resource-economics modelling techniques, the work shows that, taking selected internal and external factors into account, biological control is considered the most beneficial present and future option. The many negatives of persistent use of insecticides and herbicides are well known. To this should be added the fact that the rate of production of new pesticide molecules is currently at its lowest rate for 30 years.

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