Economic benefits of biological control of *Sitona obsoletus* (clover root weevil) in Southland pasture

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Abstract *Sitona obsoletus* is a serious pasture pest in New Zealand where its root-feeding larvae reduce white clover cover and nitrogen fixation. To maintain production, farmers may compensate by increasing inputs. The parasitic wasp *Microctonus aethiopoides* Loan was introduced for biological control of *S. obsoletus* and achieved parasitism rates exceeding 70%. In Southland, where *S. obsoletus* was first detected in 2010, unusually severe and prolonged infestations during 2013 and 2014 prompted intensive biological control releases in 2014 and 2015. This study evaluated if they were cost effective in 2015. On dairy farms biological control returned \$14.78/ha/year or \$2.3 million over the 158,017 ha. On sheep and beef farms, the estimated return was \$6.86/ha/year or \$4.7 million over 719,854 ha. Monte Carlo simulations were used to estimate returns (\$/ha/year) using plausible ranges of model parameter values, and returns were positive in at least 97.5% of simulations. Biological control of *S. obsoletus* has returned a net benefit in Southland.

Keywords cost benefit analysis, CBA, classical biological control, economic impact, Monte Carlo simulation, *S. lepidus*.

INTRODUCTION

The Palaearctic species *Sitona obsoletus* Gmelin (Coleoptera: Curculionidae), clover root weevil, was first detected in New Zealand in Waikato in 1996 (Barratt et al. 1996), after it had already become widespread in Auckland, north Waikato and coastal Bay of Plenty (Barker et al. 1996). It advanced through the North Island at 10–70 km/year (Hardwick et al. 2004) and reached the southern end of the North Island by 2005 (Gerard et al. 2009). It was first discovered in the South Island in 2006 in Christchurch, Richmond and Rai Valley (Phillips et al. 2007), and was found in Otago in 2009, Southland in 2010 (Phillips et al. 2010) and Westland in 2012 (Ferguson et al. 2012). Adults of *S. obsoletus* feed on white clover leaves and can reduce establishment of seedlings, but it

is the root-feeding larvae that cause most damage by reducing nitrogen fixation and weakening or killing white clover plants. To maintain production, farmers may apply synthetic nitrogen, grow additional non-susceptible forage plants, and/or increase supplementary feed.

A biological control agent for *S. obsoletus*, the parasitoid wasp *Microctonus aethiopoides* Loan (Hymenoptera: Braconidae), was first introduced to the North and South Islands of New Zealand in 2006 (Gerard et al. 2006; Phillips et al. 2007). In general, the distribution of the biological control agent has increased in New Zealand in tandem with that of *S. obsoletus*, both through natural parasitoid dispersal and ongoing releases (Gerard et al. 2009; Phillips et al. 2010; Ferguson et al. 2012). However, build up of

*M. aethiopoidea*s populations in a location usually lagged that of *S. obsoletus* by about 2 years, which meant farms frequently had to endure severely reduced white clover before the biological control agent could suppress the pest. By autumn 2015, both *S. obsoletus* and *M. aethiopoidea*s were present throughout New Zealand (S. Hardwick, unpublished data).

In Otago and Southland during 2013 and 2014, damage to white clover from *S. obsoletus* was particularly acute and prolonged. Contributing factors may have included: relatively high rates of inadvertent human-assisted spread of *S. obsoletus*; relatively low rates of natural dispersal of *M. aethiopoidea*s; and two successive mild winters, which promoted high *S. obsoletus* feeding and population growth, without any concomitant advantage to *M. aethiopoidea*s. These extraordinary circumstances prompted AgResearch, DairyNZ and Beef+Lamb NZ to implement an intensive programme of releasing nearly a million *M. aethiopoidea*s in Otago and Southland, during the (July to June) financial years 2013-14, and 2014-15. This paper evaluates the economic costs and benefits of the biological control releases in Southland in 2015, which is where and when the majority of releases were made.

MATERIALS AND METHODS

An economic model was developed to compare the costs and benefits (\$/ha/year) of releasing the *S. obsoletus* biological control agent in Southland. To derive a conservative net benefit, the cost savings (\$/ha) due to biological control during 2015, minus the money spent (\$/ha) to make the releases, were estimated. For simplicity, it was conservatively assumed that all release costs were attributable to Southland and they were all incurred in the 2014-15 financial year. Beyond 2015, no further releases should be necessary, thus the net benefit will be equal to the cost savings.

Where possible, model input parameters and assumptions were based on published data. However, many parameter values were uncertain, so a sensitivity analysis was conducted using Monte Carlo simulation.

Methods were based on two economic impact assessments of *S. obsoletus*, in the absence of control, on the grazing sector (Weir & Andrews 2005; Dooley & Lovatt 2013). For the present economic model, the following seven assumptions were used: (1) The economic impact of *S. obsoletus* was predominantly on dairy, and sheep and beef (SB) farms. (2) Without biological control, *S. obsoletus* reduced white clover cover and hence nitrogen fixation on both dairy and SB farms. (3) The percent reduction in clover cover equated to the percent reduction in nitrogen fixation. (4) Dairy farms compensated for reduced nitrogen fixation by applying synthetic nitrogen at rates that maintained production at pre-*S. obsoletus* levels. (5) Reduced white clover on SB farms led to lower farm profits before tax (\$/ha/year). (6) In 2015, both *S. obsoletus* and its biological control agent were present throughout Southland pastures. (7) The cost of implementing biological control of *S. obsoletus* was allocated evenly across each hectare of Southland pasture.

Table 1 details the model parameters used in the analysis. In 2013, the total area of pasture in Southland was 877,871 ha, of which 158,017 ha (18%) was dairy and 719,854 ha (82%) was SB (AsureQuality 2013).

Nitrogen fixation

Published estimates of the nitrogen fixed (kg N/year) by white clover in New Zealand, in the absence of *S. obsoletus*, ranged from 26–231 kg N/year (Weir & Andrews 2005; Ledgard et al. 1999). The Southland value of 56 kg N/year (Weir & Andrews 2005) was used as the best estimate, and the full range of reported values (Table 1) was investigated in the sensitivity analysis.

Benefit of releasing the biological control agent

The benefit (\$/ha/year) of the biological control programme was calculated as the difference between the costs saved by biological control and its implementation cost (Equation 1).

$$\left(\text{Benefit of the control programme (\$/ha/year)} \right) = \left(\text{Cost savings (\$/ha/year)} \right) - \left(\text{Implementation costs (\$/ha/year)} \right) \quad \text{Eq.(1)}$$

Table 1 Best estimate parameter values used in the economic model, and the range of values evaluated in Monte Carlo simulations.

Parameter description	Best estimate	Range	Range (% of best estimate)
Area of all pasture (ha)	877,871		
Area of dairy pasture (ha)	158,017 (18%)		
Area of sheep and beef pasture (ha)	719,854 (82%)		
Nitrogen fixation without <i>S. obsoletus</i> (kg N/year)	56	26 – 231	46 – 413
Cost of urea fertiliser (\$/kg)	0.74	0.30 – 0.80	41 – 108
Sheep and beef farm profit before tax (\$/ha/year)	130	34 – 260	26 – 200
Impacts of <i>Sitona obsoletus</i>			
Loss of nitrogen fixation (%)	50	0 – 100	0 – 200
Sheep and beef decrease in profit (%)	16	0 – 100	0 – 625
Recovery due to parasitoid (%)			
	33	0 – 100	0 – 303
Implementation costs (\$/ha)			
	0.36	–	

Cost of implementing biological control

A total of \$640,000 was spent releasing the biological control agent throughout mainly Southland pastures during 2013–14 and 2014–15. It was assumed that these annual costs (\$320,000) were allocated evenly across the Southland area of dairy and SB pasture (877,871 ha) at \$0.36/ha/year. This included the cost of collecting the biological control agent from other New Zealand regions where it was already present and distributing it to Southland farms, either directly or by providing it to farmers during field days. However, it did not include the costs of research conducted during 1996–2006 that was required to find the biological control agent and introduce it to New Zealand (Phillips et al. 2000; Goldson et al. 2001). Nor did it include the costs of releasing it in other New Zealand regions after 2006 (Gerard et al. 2008; Ferguson et al. 2012).

The implementation costs incurred by those farmers who released the biological control agent themselves would have been negligible, and were not included in the calculations. Generally they would have involved travel to a field day and a few minutes of on-farm labour to scatter parasitised *S. obsoletus* in one or more infested paddocks.

Cost of *Sitona obsoletus* and savings due to biological control on dairy farms

Many New Zealand farms suffered heavy infestations of *S. obsoletus* during the period before the biological control agent could be released, build up to high levels and suppress the pest. During this period, Waikato dairy farmers responded by applying synthetic nitrogen at levels required to maintain normal production (Weir & Andrews 2005). Similarly, at the Lincoln University dairy research farm, applications of synthetic nitrogen increased by 65% after *S. obsoletus* became established there, while annual total milk solids remained steady (Anonymous 2015). It was assumed Southland dairy farmers also increased applications of synthetic nitrogen to maintain production.

Synthetic nitrogen is usually applied as urea fertiliser, which comprises 46% elemental nitrogen. From 1990 to April 2013, the price of urea fertiliser (ex works) fluctuated between approximately \$0.30 and \$0.80 /kg (including GST) (Burt 1990, 1992, 1996, 1997, 1998, 1999, 2000, 2002, 2004, 2006; Burt & Fleming 1991, 1993, 1994; Burt & Oliver 1995; Chaston 2008; Pangborn 2010; Dooley & Lovatt 2013). For the

best estimate, a 2013 value of \$0.74 /kg (Dooley & Lovatt 2013) was used, but the full range of values (Table 1) was also evaluated in the sensitivity analysis. Costs of urea did not include freight, storage or application.

For best estimate model parameters, it was assumed that *S. obsoletus* initially reduced nitrogen fixation by 50% (Weir & Andrews 2005), with N fixation recovering by 33% of the reduced value once the biological control agent became established (Dooley & Lovatt 2013). These values were based on experts' opinions, but no data were available to verify them. A 33% recovery accounts for the probability that some *S. obsoletus* damage to white clover will persist after biological control is implemented. For the sensitivity analysis, these values were varied between 0 – 100% (Table 1). Cost savings on dairy farms were estimated with Equation 2.

Cost of *Sitona obsoletus* and savings due to biological control on sheep and beef farms

Few data were available to quantify the impact of *S. obsoletus* on SB farms. Badly affected farms would have incurred production losses, such as slower lamb growth rates (J. Risk, Ballance Agri-Nutrients Ltd, personal communication) or inability to graze dairy cattle in winter (C.M. Ferguson, AgResearch, personal communication). Some possible management responses included increased use of supplementary feed, cultivating additional non-susceptible forage plants and applying additional nitrogen fertiliser. Irrespective of the response, *S. obsoletus* would have reduced SB farm

profits (\$/ha/year) (Sinclair & Rennie 2014). A simulation of SB farms in Waikato showed a 16% reduction in annual gross margins due to *S. obsoletus* (White & Gerard 2006). Thus, it was assumed the impact in Southland was a 16% reduction in farm profit before tax (\$/ha), followed by a 33% recovery due to biological control. For the sensitivity analysis, both of these values ranged between 0 – 100% (Table 1).

From 2005 to 2014, SB farm profits before tax in Otago and Southland ranged from \$34/ha to \$260/ha, with an average of \$130/ha (Beef+Lamb NZ 2015). Cost savings on SB farms were estimated by Equation 3.

Sensitivity analysis

A Monte Carlo simulation was used to sample model input parameters (Equations 2 & 3) from triangle distributions defined by their minimum, most likely and maximum values (Table 1). The range of estimated benefits was plotted from 100,000 stochastic simulations. For comparison, this process was repeated with input parameters sampled from uniform distributions defined by their minimum and maximum values. To evaluate the influence of using triangle and uniform parameter distributions on the results, Mann-Whitney Wilcoxon tests were used to identify significant differences between benefit distributions differentiated by farm type (dairy versus SB).

All programming and statistical tests were performed using the software R (R Development Core Team 2014) and the R package 'triangle' (Carnell 2015).

$$\left(\begin{array}{c} \text{Sheep and beef cost savings} \\ (\$/\text{ha}/\text{year}) \end{array} \right) = \left(\begin{array}{c} \text{Farm profit before tax} \\ (\$/\text{ha}/\text{year}) \end{array} \right) \times \left(\begin{array}{c} \text{Farm profit decrease} \\ (\%) \text{ due to pest} \end{array} \right) \times \left(\begin{array}{c} \text{Recovery } (\%) \\ \text{due to biological control} \end{array} \right) \quad \text{Eq. (2)}$$

$$\left(\begin{array}{c} \text{Dairy cost savings} \\ (\$/\text{ha}/\text{year}) \end{array} \right) = \left(\begin{array}{c} \text{Normal N} \\ \text{fixation (kg N/ha/year)} \end{array} \right) \times \left(\begin{array}{c} \text{Reduced N fixation} \\ (\%) \text{ due to pest} \\ \text{46\% N content} \\ \text{of urea} \end{array} \right) \times \left(\begin{array}{c} \text{Cost of urea} \\ (\$/\text{kg}) \end{array} \right) \times \left(\begin{array}{c} \text{Recovery } (\%) \\ \text{due to biological control} \end{array} \right) \quad \text{Eq. (3)}$$

Table 2 Costs and benefits of implementing a biocontrol programme for CRW, on dairy and sheep and beef farms in Southland using best estimate model parameters.

	Dairy	Sheep and beef
Cost of implementing biological control (\$/ha/year)	0.36	0.36
Cost saving due to biological control (\$/ha/year)	14.78	6.86
Benefit (\$/ha/year)	14.42	6.50
Pasture in Southland (ha)	158,017 (18%)	719,854 (82%)
Benefit in Southland (\$ million/year)	2.3	4.7

RESULTS

Best estimate model parameters

On dairy farms, a 50% reduction in nitrogen fixation due to *S. obsoletus* required 60.9 kg urea/ha/year to replace it (28 kg N/ha/year at 46% N content of urea) at a cost of \$44.80/ha/year ($60.9 \times \0.736). With a subsequent 33% recovery due to biological control, cost savings were $0.33 \times \$44.80 = \14.78 /ha/year (Equation 2). Hence the benefit (Equation 1) of implementing biological control on Southland dairy farms, using the most likely model parameters, was estimated as \$14.42/ha/year, or \$2.3 million/year over the 158,017 ha of Southland dairy pasture (Table 2).

On SB farms, a 16% reduction in farm profits before tax due to *S. obsoletus* would cost \$20.80/ha/year (16% of \$130). With a subsequent recovery

of 33% due to biological control, cost savings were \$6.86/ha/year ($0.33 \times \20.80) (Equation 2). Hence the benefit (Equation 1) of implementing biological control on Southland SB farms, using our most likely model parameters, was estimated as \$6.50/ha/year, or \$4.7 million/year over the 719,854 ha of SB pasture in Southland (Table 2).

The combined benefit of implementing biological control for dairy and SB farms in Southland, based on the most likely model parameters, was \$2.3 million + \$4.7 million = \$7.0 million/year, or \$7.97/ha/year.

Sensitivity analysis

When the minimum and maximum values of model input parameters were used (Table 1), the benefit on dairy farms (Equations 1 & 2) ranged

Figure 1 Distributions of benefits (\$/ha/year) on both dairy (a & c) and sheep and beef (SB) (b & d) farms, when input parameters were sampled 100,000 times either from triangle (a & b) or uniform (c & d) distributions.

Figure 2 Boxplots for the benefits (\$/ha/year), both on dairy and on sheep and beef (SB) farms, when input parameters were sampled 100,000 times from triangle (T) and uniform (U) distributions.

from $-\$0.36$ to $\$401.37$ /ha/year, and the benefit on SB farms (Equations 1 & 3) ranged from $-\$0.36$ to $\$260$ /ha/year.

When each parameter was sampled from a triangle distribution, benefits on dairy farms ranged from $-\$0.34$ to $\$320.50$ /ha/year, with a median of $\$22.80$ /ha/year; 95% of benefits were between $\$2.30$ and $\$101.17$ /ha/year (the 2.5% and 97.5% percentiles, respectively) (Figure 1a). On SB farms, benefits ranged from $-\$0.33$ to $\$218.30$ /ha/year, with a median of $\$17.54$ /ha/year; 95% of benefits were between $\$1.44$ and $\$80.76$ /ha/year (Figure 1b & Figure 2).

When each parameter was sampled from a uniform distribution, benefits on dairy farms ranged from $-\$0.36$ to $\$356.30$ /ha/year with a median of $\$22.21$ /ha/year; 95% of benefits were between $\$0.04$ and $\$160.94$ /ha/year (Figure 1c). On SB farms, benefits ranged from $-\$0.36$ to $\$252.40$ /ha/year, with a median of $\$22.62$ /ha/year; 95% of benefits were between $\$0.09$ and $\$144.11$ /ha/year (Figure 1d & Figure 2).

When parameter inputs were sampled from triangle distributions, the distribution of benefits (\$/ha/year) for dairy was significantly greater than for SB (Mann-Whitney test, P -value $< 2.2 \times 10^{-6}$, one-tailed). When parameter inputs were sampled from uniform distributions, there was no significant difference between dairy and

SB (Mann-Whitney test, P -value = 0.5726, one-tailed). Thus, choice of parameter distribution strongly influenced the results.

DISCUSSION

The present economic model for *S. obsoletus* progressed previous models by using more recent data, more accurately accounting for implementation costs, treating SB and dairy farms separately and conducting a comprehensive sensitivity analysis.

Using best estimate model parameters, in 2015 biological control returned a benefit to Southland dairy farms of $\$14.42$ /ha/year, and to SB farms of $\$6.50$ /ha/year. However, due to the larger area of SB pasture in Southland, the SB sector appeared to benefit more overall from the programme than the dairy sector ($\$4.7$ M/year cf. $\$2.3$ M/year).

When taking parameter uncertainty into account, *S. obsoletus* biological control in Southland returned a positive benefit to dairy and SB farms in at least 97.5% of simulations. This confirms that the biological control releases were overwhelmingly profitable, irrespective of the model parameters chosen. However, choice of parameter distribution determined whether differences in the distributions of benefits assigned to SB and dairy were significantly different. As there is no information about which parameter distribution is most correct, it cannot be determined whether one farm type benefited more from the releases than another.

Dairy benefits were significantly greater than SB benefits when parameters were sampled from triangle rather than uniform distributions. This was because the best estimate of benefits for dairy was greater than for SB, but the ranges of possible benefits for dairy and SB were similar. Thus, the triangle distributions, which contained more parameter values close to the best estimates, gave higher benefits for dairy, but the uniform distribution produced estimates that were broadly similar for both farm types.

Previously published estimates of the economic impact of *S. obsoletus* for all of New Zealand (Willoughby et al. 1999; Barlow & Goldson 2002; ERMA 2005; Weir & Andrews 2005; Dooley & Lovatt 2013) have ranged from

\$18.98/ha/year (\$200M/year over 10,538,079 ha; Weir & Andrews 2005) to \$296.80/ha/year (2.4B/year over 8,086,160 ha; Dooley & Lovatt 2013). Previously published estimates of the economic benefits of *S. obsoletus* biological control in New Zealand ranged from \$5.93/ha/year (\$80M/year over 13,500,000 ha; ERMA 2005) to \$18.55/ha/year (\$150.2M/year over 8,086,160 ha; Dooley & Lovatt 2013). These previous analyses thus gave benefits that were within the range of the present estimates.

The present analysis underestimated the total impact of *S. obsoletus*, and thus the benefit of biological control, because it considered neither the full range of possible impacts on dairy and SB farms, nor impacts on other sectors that also profit from white clover. For example, potential impacts on dairy and SB farms that were not factored into the analysis include: costs of transporting, storing and applying urea; increased requirement to implement break crops or fallow periods between pasture renovations (C.M. Ferguson, AgResearch, personal communication); reduced success of sowing clover into existing pasture (C.M. Ferguson, AgResearch, personal communication); increased animal health risks (Andrews 1966; Sherrell 1990; Anonymous 2000; Lambert et al. 2004); and lower earthworm counts (Watkin & Wheeler 1966). Sectors additional to dairy and SB that could be impacted by *S. obsoletus* include apiculture and deer. For example, Weir & Andrews (2005) estimated that once *S. obsoletus* was distributed throughout New Zealand, without control it would cost the apiculture industry \$16.5M/year under their medium impact scenario. Such impacts could be included in the present model and apportioned to Southland in future work.

The present analysis also underestimated the impact of *S. obsoletus*, and thus the benefit of biological control, because it did not consider environmental impacts. For example, Weir & Andrews (2005) accounted for greater greenhouse gas emissions arising from increases in both urea production and fertiliser applications due to *S. obsoletus*, which amounted to 5.6M/year under their medium impact scenario. However,

they also assumed that all New Zealand farms, once infested with *S. obsoletus*, would maintain production either by applying extra nitrogen fertiliser or by using additional supplementary feed. On many Southland SB farms, extra nitrogen fertiliser could be unaffordable depending on its price (J. Risk, Ballance Agri-Nutrients Ltd, personal communication), thus environmental costs would be traded for economic costs.

The next stages of this research will be to include the following factors in the economic analysis: the research costs of finding and introducing the *S. obsoletus* biological control agent to New Zealand; factoring-in the gradual spread of *S. obsoletus* and its biological control agent throughout New Zealand; and estimating the benefits of *S. obsoletus* biological control in other New Zealand regions. The methods presented in this paper will provide a basis for estimating the benefits of future biological control programmes in New Zealand.

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