Ministry for Primary Industries
Manatū Ahu Matua

Economic costs of pests to New Zealand

2020 Update

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New Zealand Government

MPI Summary

BACKGROUND

This report was produced for MPI by Nimmo-Bell & Associates.

In September 2009, Nimmo-Bell prepared the report "Economic Costs of Pests to New Zealand" for MAF Biosecurity New Zealand (MAF Biosecurity New Zealand Technical Paper No: 2009/31).

In 2019, the Ministry for Primary Industries started a review of the Biosecurity Act 1993. As part of that work programme, MPI commissioned Nimmo-Bell to update the 2009 report and to provide data on additional impacts that were not included in the 2009 report.

SUMMARY

This report by Nimmo-Bell has used the same methodology to update the 2009 report and has added estimated costs from new invasive pests.

Defensive expenditures, that is spending to prevent pests establishing in New Zealand and to manage established pests, increased by 43% to $1.5 billion compared to 2009. Additional defensive expenditures were across three areas:

- Responses to biosecurity incursions, for example, the Mycoplasma bovis response cost $203 million in 2019-20 the costs of which were shared between Government, the dairy and the beef industries.
- Increased expenditure on pest management, for example Predator Free 2050 was established in 2017 and in 2019-20 spent $12 million from Vote Conservation, supported by more than $26 million of local Government spending and matched by private sector spend.
- Increased primary industry expenditure on pest management as sectors have grown. For example, the number of beehives in New Zealand has increased from 360,000 in 2009 to 880,000 in 2019 and apiarists spent an estimated $14 million to manage varroa in 2019.

Defensive expenditure as a share of GDP remained stable from 0.55% in 2009 to 0.54% in 2020.

Output losses, that is the estimated cost of primary sector production losses from pests, increased to over $4.3 billion in 2020 compared to $1.5 billion in 2009. The causes of increases in estimated production losses are from:

- substantial increases in the value of primary sector production, meaning that the value of losses has also increased, and
- new research over the past decade that has added estimates of losses from twelve more established pests than used in the 2009 report.

The report estimates the total economic costs of pests to New Zealand to be $9.2 billion in 2019/20 – 2.9% of GDP. The total economic value of pests in the 2009 report was $4.2 billion – 1.9% of GDP.

Broader analysis of non-market impacts on New Zealand's four important biosecurity values of environmental, cultural, social, and economic wellbeing is proposed to supplement the results from this report.

In addition to supporting the Biosecurity Act review, information from this report will help inform Treasury's review of natural resources sector spending, support budget bids by Biosecurity New Zealand and other departments, and assist regional councils and primary sector industries in budgeting of pest management plans.

MPI would also like to thank Regional Biosecurity Managers Group for their assistance to Nimmo-Bell in the preparation of this report.

Final report

Economic costs of pests to New Zealand: 2020 update

13 August 2021

NIMMO-BELL & ASSOCIATES
A Division of the Prime Group

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Acknowledgements

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1 Executive summary

This report is an update of the Economic Costs of Pests to New Zealand (2009). It details the defensive expenditure of Government, Local Authorities and the private sector in response to invasive pests and weeds. It also details productivity losses to the private sector associated with these invasive species. The trends and new data have been assessed and analysed, and implications for biosecurity have been identified.

Defensive expenditures rose by 12 percent to $1.2 billion compared to a like-for-like the 2009 (inflation adjusted) baseline[1]. The largest contributor to this increase was central government expenditure, which like-for-like increased by $83.5 million. Regional Council expenditure experienced the highest like-for-like growth rate at 69 percent, influenced by Predator Free 2050 initiatives. With the inclusion of new expenditures in response to biosecurity incursions, total defensive expenditure grew by 40 percent to $1.5 billion (GST exclusive) in 2019-20. As a share of GDP, defensive expenditure[2] has remained fairly stable from 0.55 percent in 2009 to 0.54 percent in 2020 despite the primary sector's declining share of total GDP from 5.61 percent in 2009 to 5.24 percent in 2020.

Utilising the same list of invasive species as that used in Nimmo-Bell (2009), annual primary sector production losses are estimated to be over $2.4 billion in 2020, an increase of 55 percent over the 2009 inflation adjusted amount. While the prevalence or biological impact of many of the invasive species has decreased since 2009, substantial increases in the value of primary sector production has meant that the overall economic impact has increased dramatically. Also, a change in loss calculation methodology (to a national model from a regional basis in 2009) has resulted in a very significant change to the economic impact of the Californian thistle, up to $751 million from $26 million. Rabbits are one of the few species whose prevalence appears to have increased, as has the spread of Gum Leaf Skelentoniser into South Waikato and the wider Bay of Plenty.

New academic research and methodologies have provided production loss estimates for a larger number of invasive species, including a greater number of pastoral invertebrate pests, invasive weeds, and wilding conifers. In total, production losses are now estimated at $4.3 billion, with pastoral invertebrate pests accounting for $1.5 billion of the $1.9 billion in additional invasive species production losses.

Combining defensive expenditures and production losses, the total economic cost of pests to New Zealand's primary sector is estimated to be almost $6 billion (including GST) in the 2019-20 financial year. This represents a 118 percent increase on the 2009 estimate (adjusted for inflation). Of the $6 billion estimate, defensive costs represent 28 percent, and production losses 72 percent. This is a different mix from the 2009 report which had defensive costs at 43 percent, and production losses at 57 percent. This result is driven by higher primary sector production values (and hence proportionately greater lost production due to pests), and the availability of estimates for more invasive species. The increase in primary production value is driven in part by higher commodity prices rising by an average 47 percent since 2009.

Applying an economic multiplier to the production losses, in order to account for the upstream and downstream impacts of pests on primary sector output and Gross Domestic Product (GDP), provides a total economic cost of defensive expenditure and production losses at an estimated $9.2 billion. This represents 2.9 percent of GDP, a significant increase from the 1.9 percent in 2009, despite the primary sector's shrinking share of total GDP.

[1] The scope of this report required two levels of comparative analysis: (a) comparison to the figures provided in the 2009 report on a like-for-like basis and (2) inclusion of new expenditures and production losses to assess impact of new biosecurity incursions or activities. Throughout this report, the first comparison is like-for-like with the 2009 report and the second comparison includes impact of new incursions or activities.

[2] Defensive expenditure is converted to GST inclusive when assessed as a share of GDP.

While biosecurity spend on a 2009 like-for-like basis has declined as a percentage of primary sector GDP, biosecurity incursions have led to new spending. This has resulted in defensive expenditure expanding to 10.8 percent of primary sector GDP from 9.0 percent in 2009. With the growing value of primary sector output, coupled with additional invasive species, production losses inclusive of multiplier effects have been magnified, and have risen by 151 percent (accounting for a larger, 82 percent share of the total economic cost of pests). This implies greater benefits in biosecurity investment to control pests.

To assess the net economic benefit of biosecurity investment for a specific pest (among policy options of do nothing, control, and eradication among others), a decision support tool is needed such as the CBA framework under development from the research project *M. bovis*: Measuring Economic Impacts of Biological Incursions. Gaps in studies, such as prevalence data and robust impact assessments inhibit accurate estimation of production losses for a number of mammalian pests. Such data is critical to cost benefit analysis and the justification and/or prioritisation of biosecurity investment. The discontinuation of farm monitoring reports has prevented the capture of defensive expenditures for some industries. The lack of comprehensive data of industry contribution towards GIA funding and resulting expenditures may have underestimated private sector defensive expenditures.

Government funding and expenditure now also consists of a web of different initiatives and programmes, with previous business-as-usual expenditure blended with new investment. Science funding in particular is difficult to untangle, with differing bodies (MPI, MBIE) providing funding through differing mechanisms (Science Challenges, Sustainable Food and Fibre Fund), to differing research bodies who work collaboratively but record expenditure differently.

2 Introduction

The Ministry for Primary Industries is reviewing the Biosecurity Act and commissioned this update of the 2009 report "Economic Costs of Pests to New Zealand". The report estimates defensive expenditure by Government, Local Authorities and the private sector and productivity loss to the private sector based on the 2009 repeatable methodology. The primary objective is to compare the 2008 baseline with updated 2020 figures to track changes over the last 12 years. A secondary objective is to improve accuracy and coverage of pest costs estimates, if possible, from additional sources of data and research or new approaches.

This report adopts similar methodology as the 2009 report comprising defensive expenditures and output losses. Defensive expenditures refer to the costs to control pest and weeds while output losses are the losses after the control expenditures (i.e. residual losses). This occurs either due to scope (i.e. not all pests and weeds are covered) and intensity (i.e. light vs intense control activities) of control expenditures. The CBA undertaken by Regional Councils for pest management quantifies the potential avoided output losses (benefits) due to pest management expenditures (costs).

The defensive expenditures were collected from:

- The 15 Regional Councils via the Regional Biosecurity Managers Group
- Central Government ministry/department annual reports and MPI data via the Biosecurity Act Review Team
- Industry data from published economic surveys, levy body annual reports and farm monitoring reports via the Biosecurity Act Review Team.

The production losses were sourced from a literature review of New Zealand research on pests and weeds from the 2009 report and additional pests and weeds that were not covered in the 2009 report or new biosecurity incursions. These losses were adjusted for 2020 variables such as number of hectares, prevalence or industry production.

The scope of work follows the 2009 report with a main focus on pests to the primary sectors (agriculture, forestry, fisheries, horticulture). Pests are also limited to major plant and animal pests and do not include diseases such as Bovine TB (although the control of TB vectors is included) and/or microbial pests such as nematode worms in livestock or fungal diseases in forestry although exceptions were made for major incursions such as *Mycoplasma bovis, Pseudomonas syringae pv. Actinidiae* and *Paenibacillus larvae* causing American Foulbrood. Broader analysis of non-market impacts covering biodiversity, taonga species, loss of amenity values, social, cultural, environmental values affected by pests, along with linkages to existing work at Ministry for Environment, Statistics New Zealand and Department of Conservation is out of scope for this report, but may be undertaken as a separate piece of work in future.

This report analyses the findings, assesses the trends and new information, and draws conclusions on implications for the biosecurity system (similar to Chapter 4 of the 2009 report). The structure of the report begins with this introduction. The next two sections (sections 3 and 4) quantify and compare defensive expenditures and output losses based on the same scope as the 2009 report. Section 5 identifies and quantifies additional defensive expenditures and output losses that have developed since 2009. Section 6 assesses the total economic costs of pests and weeds as well as the economic multiplier impact of production losses. The report ends with conclusions on implications for the biosecurity system.

3 Defensive expenditures

3.1 Local government

While the 2009 report showed local government expenditures for plant and animal pests, 2019-20 cost estimate classifications were expanded[3] to distinguish freshwater and marine pests, as well as overheads, training and other non-specific costs (Table 1). Most Regional Councils provided this breakdown of defensive expenditure.

Table 1. Annual pest and weed expenditure by Regional Council 2019-20 ($'000)

Regional Council	Animals	Plants	Freshwater	Marine	Overheads/other	Total
Northland	2,246	1,442	63	646	2,508	6,905
Auckland	4,022	2,813	293	187	9,210	16,525
Waikato	4,305	3,561				7,866
Bay of Plenty	1,045	1,979	956	640	1,123	5,743
Hawke's Bay	2,761	1,032		102	105	4,001
Gisborne	596	404	10	30	368	1,409
Manawatu-Wanganui	4,458	1,788				6,247
Taranaki	2,385	1,590				3,975
Greater Wellington	4,958	1,499	20		1,840	8,318
Tasman	392*			6	234	632
Marlborough	1,291*				403	1,694
West Coast			16		124	139
Canterbury	1,402	3,399	72		2,717	7,590
Otago	657	519	120			1,296
Southland	919	703	5	285	1,346	3,259
Total (GST exclusive)	**31,439**	**20,730**	**1,554**	**1,896**	**19,978**	**75,598**

Source: Personal communications with each Regional Council[4]

* Included in 'Animals' total

[3] On the suggestion of the regional biosecurity managers

[4] Facilitated through Regional Biosecurity Managers Group

The majority of Regional Councils have increased expenditure over the past decade. Local government expenditure on pest and weed control totalled $75.6 million for the 2019-20 financial year. This represents a 69 percent increase from the 2009 figure of $44.7 million (inflation adjusted into 2020-dollar terms). Many of these regional increases are associated with Predator Free 2050 initiatives[5]. Regional councils contribute to Predator Free 2050 through their business-as-usual predator control activities. The total investment into Predator Free 2050 initiatives by local government is estimated to be more than $26 million annually (DOC, 2021).

Table 2. Changes in Regional Council weed and pest expenditure (2009 inflation adjusted; $'000)

Regional Council	2019-20	2009 estimates in 2020 dollars	% Change
Northland	6,905	1,453	375%
Auckland	16,525	6,116	170%
Waikato	7,866	6,949	13%
Bay of Plenty	5,743	3,270	76%
Hawke's Bay	4,001	2,769	44%
Gisborne	1,409	1,003	40%
Manawatu-Wanganui	6,247	4,249	47%
Taranaki	3,975	2,512	58%
Greater Wellington	8,318	2,859	191%
Tasman	632	850	-26%
Marlborough	1,694	1,290	31%
West Coast	139	12	1049%
Canterbury	7,590	4,548	67%
Otago	1,296	969	34%
Southland	3,259	5,813	-44%
Total (GST exclusive)	**75,598**	**44,663**	**69%**

Source: Personal communications with each Regional Council[2]

[5] Predator Free 2050 is an umbrella initiative to rid New Zealand of three introduced predators: possums, mustelids (ferrets, stoats, weasels) and rats. Funding for Predator Free activities are a mix of business-as-usual expenditure and targeted investment. Alongside the estimated $26 million spend from local government, central government and private sector spend approximately $75 million annually on Predator Free activities (DOC, 2021). Within this report, central government and private sector expenditures are captured within DOC's Pest Management expenditure (Table 3), OSPRI (Table 4), and Predator Free 2050 Limited (Table 6).

3.2 Central government

Based upon the agencies used in Nimmo-Bell (2009), annual central government weed and pest expenditure is estimated in Table 3, totalling $590.5 million in the 2019-20 financial year. Direct comparisons with 2009 spending by activity have not been possible due to changes in accounting and reporting lines, however overall changes by agency are shown. Overall, central government expenditure has increased by 16 percent from the 2009 (inflation-adjusted) figure of $507 million.

Table 3 also includes a comparison of science and research funding by central government in 2009 and 2020. Both estimates are likely to be understated due to changes in science and research programmes. The 2007 'Biosecurity Science Strategy for New Zealand' was used as the basis for central government expenditure in the 2009 report ($37 million, adjusted for inflation to $44.8 million), however no such equivalent science strategy currently exists. The closest equivalent programme is the Biological Heritage National Science Challenge, hosted by Landcare Research, which has a 10-year budget of $63.7 million (starting 2014). This is the largest contributor to Landcare's overall biosecurity research spend of $17.5 million in 2019-20.

Table 3. Estimated biosecurity, pest management and related research expenditure by central government 2019-20 vs 2008-09 ($'m)

Agency	Activity	2019-20	2009 estimates in 2020 dollars	% Change
Customs	Clearance and enforcement services	174.5	144.1	21%
MPI	Border Biosecurity - Monitoring and clearance	129.4	223.0	6%
MPI	Border Biosecurity - Systems dev. and maintenance	21.2		
MPI	Biosecurity incursion response pest management	28.0[6]		
MPI	Domestic biosecurity surveillance	46.5		
MPI	Biosecurity Policy Advice	4.0		
MPI	Implementation of Biosecurity Policy Advice	7.2		
DOC	Pest management (incl. Predator Free activities)	148.0	92.0	64%
DOC	Crown contribution to regional pest management	2.7		
LINZ	LINZ biosecurity programme	6.7	3.0	121%
Landcare	Biosecurity science research	17.5	44.8	-50%
AgResearch	Pastoral sector weed research	3.9		
MPI/Industry	Sustainable Food and Fibre Futures	0.8		
	Total (GST exclusive)	**590.5**	**507.0**	**16%**

Source: Annual reports and government statistics[7]

[6] Excludes expenditure relating to *M. Bovis*, wilding conifers and kauri long term management. These expense activities were not present in 2009, and as such are included as 'additional' expenses in Table 6.

[7] Customs (2020 p.73), MPI (2020 p.58-59 and 2021), DOC (2020 p.55, and 2021a p.2), LINZ (2020 p. 73), Landcare Research (2020 p.13), AgResearch (2018 p. 23).

3.3 Private sector

Based upon the sectors included in Nimmo-Bell (2009), private sector on-farm weed and pest control expenditure is estimated to have been $504.5 million in the 2019-20 financial year. This is a slight increase of 2 percent over the inflation adjusted estimates from 2009 of $493.5 million. These sector estimates are based upon various industry and financial sector farm monitoring reports, with average on-farm costs extrapolated to provide a sector-wide estimate. The assumptions, calculations and source data for each of these estimates is provided in Appendix 1.

Sheep, Beef and Deer expenditures have increased substantially in recent years. From 2011-12 to 2016-17, annual expenditures averaged about $13,750 per farm, before jumping to approximately $18,750 from 2017-18 (BLNZ, 2021). This increase is likely to be driven by improved farm returns, with pest and weed expenditures consistently hovering around 3 percent of farm revenue.

OSPRI's $77.8 million spend has been split between TB control and NAIT/other activities (which have been include in Table 6 as additional expenses). This is to provide a comparison to the expenses of the former Animal Health Board in the 2009 report.

Table 4. Estimated private sector cost of on-farm weed and pest control 2019-20 vs 2008-09 ($'m)

Sector	2019-20	2009 estimates in 2020 dollars	% Change
Dairy	59.2	58.1	2%
Sheep, Beef and Deer	115.4	102.9	12%
Arable	61.4	63.0	-3%
Pipfruit	30.8	30.4	1%
Viticulture	45.1	38.7	17%
Kiwifruit	18.3	21.4	-14%
Vegetables	49.4	49.4	0%
Other horticulture	12.1	12.1	0%
	391.8	376.0	4%
Industry body			
OSPRI (TB Control; incl Predator Free activities)	55.1	66.6	-17%
Households	57.6	50.9	13%
Total (GST exclusive)	**504.5**	**493.5**	**2%**

Source: Industry and government statistics, see Appendix 1

4 Output losses

Utilising the same list of invasive species as that used in Nimmo-Bell (2009), annual primary sector production losses are estimated to be over $2.4 billion in 2020, an increase of 55 percent from the 2009 inflation adjusted amount.

As with the methodology in Nimmo-Bell (2009), a number of previous scientific studies, estimates of annual production losses and various industry data sources have been collated to produce this overall estimate. These are presented in Table 5, which provides estimated production losses for each of the invasive species grouped as animals, insect/invertebrate, plant, and aquaculture/waterways/marine. The assumptions, calculations, and relevant sources for each species are detailed in Appendix 2 – 2b.

While the prevalence or biological impact of many of the invasive species has decreased since 2009, substantial increases in the value of primary sector production has meant that the overall economic impact has increased dramatically. The value of honey for example has quadrupled since 2009, increasing the economic cost of varroa mite and wasps, while grape production and value has also increased leading to a high economic impact from bird pests.

A change in loss calculation methodology has resulted in a very significant change to the economic impact of the Californian thistle. A new national loss calculation (Bourdot *et al.*, 2016) of $751m far eclipses the $26m in Nimmo-Bell (2009) (which referenced a regional study). The authors (Bourdot *et al.*, 2016) note that their new modelling indicates a significant underestimation for pastoral weed production loss (of $1.2b in Bourdot *et al.*, 2007, Saunders *et al.*, 2017).

Rabbits are one of the few species whose prevalence appears to have increased since 2009, and coupled with a near doubling in sheep prices, their economic impact now nears $200 million per annum (an increase of over 220%). The Gum Leaf Skelentoniser has now spread into South Waikato and the wider Bay of Plenty, which when coupled with improved forestry returns has increased the production losses from this pest.

Recent research and a better understanding around the spread and impact of Didymo, Sea squirt and *Didemnum vexillum* have decreased their production loss impact since 2009.

Changes in individual species production losses between 2009 and 2020 are shown in Appendix 3.

Table 5. Common invasive species and associated annual production losses 2019-20 vs 2008-09 ($'m)

Species	Reference	Annual cost in 2020 dollars	2009 annual costs in 2020 dollars	% change
Animal				
Possums	(UMR, 2014 and OSPRI, 2021)	39	63	-38%
Rabbits	(Bertram, 1999)	195	61	222%
Birds - viticulture	(Kross et al., 2012)	20	12	65%
Birds - arable	(FAR, 2008)	40	40	-1%
Insect/invertebrate				
Clover root weevil	(Ferguson et al., 2018)	235	378	-38%
Argentine stem weevil	(Ferguson et al., 2018)	180	194	-7%
Varroa mite	(Landcare Research, 2020)	39	18	117%
Rose grain aphid	(van Toor et al., 2016)	7	15	-55%
Lucerne weevil	(Goldson et al., 2005)	10	10	0%
Wasps	(Bertram, 1999 and Landcare Research, 2020)	8	2	249%
Gum leaf skeletoniser	(MAF, 2003 and Forest Health News, 2016)	32	16	101%
Plant				
Giant buttercup	(Bourdot et al. 2003)	223	214	4%
Californian Thistle	(Bourdot et al. 2015)	722	31	2194%
Gorse	(Williams & Timmins, 2002, and Saunders et al. 2017)	76	38	102%
Blackberry	(Saunders et al. 2017)	8	7	4%
Forestry sector	(Saunders et al. 2017)	361	259	39%
Powdery mildew	(Bertram, 1999 and Hort NZ, 2019)	8	11	-26%
Aquaculture/waterways/marine				
Didymo	(NZIER, 2006 and Kilroy, 2014)	1	29	-97%
Sea squirt	(Soliman & Inglis, 2018)	7	18	-61%
Didemnum vexillum	(Fletcher, Forrest & Bell, 2013)	1	1	0%
Other (guess 10%)		221	151	46%
Total (GST Inclusive)		**2,433**	**1,568**	**55%**

5 Defensive expenditure and output losses since 2009

This section provides estimates of additional expenditures and production losses that have developed since the original 2009 report. Expenditure items are generally in response to biosecurity incursions (such as *Mycoplasma bovis* and *Pseudomonas syringae pv. Actinidiae*; Psa)[8], while additional production losses are the result of new academic research, understanding and methodology.

5.1 Additional defensive expenditure

The most significant additional defensive expenditure has been the response to *Mycoplasma bovis*. Direct costs associated with the incursion were $149 million in 2019-20 (MPI, 2020), while compensation and ex-gratia payments to affected farmers amounted to $53.8 million. Other additional expenditures for MPI include wilding conifer management ($17.8 million) and kauri long-term management ($2.5 million).

Predator Free 2050 Limited had total expenditures of $11.9 million in 2019-20 (PF2050, 2020), combining with the Department of Conservation's pest management expenditure (Table 3) and that of OSPRI (Table 4) to constitute the bulk of the national Predator Free spend (DOC, 2021).

Another example of central government expenditure is the significant cost NZTA incurs in controlling vegetation and weeds in the 11,000-kilometre state highway corridor. Estimates range from $240 to $730 per km per year, with an estimate of $500 per km per year used in economic modelling (NZTA 2006). Adjusting for inflation and the adoption of low-growth roadside plantings provides an estimate of $5.5 million for the 2019-20 financial year.

For the private sector, apiary sector costs are estimated at $14.3 million, and is made up entirely of the per hive cost of treatments to counter varroa mite (see Appendix 1). *Pseudomonas syringae pv. Actinidiae* (Psa) has caused kiwifruit orchard pest and weed expenses to jump from $1,300 per hectare in 2013 to $2,400 in 2015 (settling at around $2200-2300 since; ANZ 2019). This difference is captured in Table 6, with a baseline expenditure shown in Table 4.

Other industry sectors were investigated, including poultry, pork and three aquaculture sub-sectors (King salmon, Greenshell mussels and Pacific oysters). While each sector has defined biosecurity protocols for farmers (PIANZ, 2015, NZ Pork, 2021, Aquaculture NZ, 2021), the low number of producers mean that farm level benchmarks and sector-wide estimates are unavailable.

Kiwifruit Vine Health (KVH) was established as an industry levied-body dedicated to preventing the introduction of new pests and diseases into kiwifruit orchards, along with response planning. The estimate of $3.7 million is based upon levy rates and 2019-20 production volumes (Appendix 1). Levies paid by beekeepers towards the National American Foulbrood Pest Management Plan (AFB, 2020) are also included in Table 6.

OSPRI's responsibilities now also include the National Animal Identification and Tracing (NAIT) scheme, which has a primary concern with biosecurity, and has therefore been included under the estimate of additional expenditure.

There may be an underestimation of private sector spend through levy bodies. The Government Industry Agreement (GIA) is an important development since the 2009 report, with signatories sharing the decision-making, responsibilities and costs of preparing for – and responding to – biosecurity incursions. The GIA Deed came into effect formally in May 2014, when it was signed by KVH and the Ministry for Primary Industries. Most of the GIA and levy spend of industry bodies for biosecurity are accounted in the entity that makes the final expenditure.

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[8] The inclusion of Mb and Psa into additional defensive expenditures is a grey area in scope as bacteria and virus are generally excluded from scope of pests and weeds although Mb and Psa are major biosecurity incursions. NAIT similarly falls into the grey area as its main biosecurity purpose is to target microbial pathogens.

For example, Dairy NZ's funding of biosecurity activities has not been separately accounted for, as this is largely channelled through OSPRI, and has been accounted for under OSPRI's annual expenditure. Similarly, industries' GIA contributions to the *Mycoplasma bovis* incursion are coursed through and have been accounted for in MPI's response expenditure and the kiwifruit industry via KVH. As there is no comprehensive data on GIA-related levies and the biosecurity spend of levy bodies that need to be reconciled with entities that make the final expenditure to avoid double-counting, private sector spend is likely to be underestimated.

Table 6. Additional annual weed and pest expenditure estimates 2019-20 ($'m)

	Activity	2019-20
Central Government[9]		
MPI	Response to *Mycoplasma Bovis*	148.9
MPI	Compensation and ex-gratia payments in response to *Mycoplasma Bovis*	53.8
MPI	Kauri long term management	2.5
MPI	Wilding conifer management	17.8
Predator Free 2050 Limited		11.9
NZTA	Road verge vegetation control	5.5
Industry sector		
Apiary	Cost of Varroa treatment	14.3
Kiwifruit	Additional orchard operating expense due to Psa	10.1
Industry body		
OSPRI	NAIT and other costs	22.6
Kiwifruit Vine Health	PSA and Biosecurity Readiness levies	3.7
National American Foulbrood Pest Management Plan		1.06
Total (GST exclusive)		**292.2**

[9] The $1.219 billion 'Jobs for Nature' package was not established until the 2020-21 financial year, and therefore falls outside 2019-20 financial year window of this report.

5.2 Additional output losses

Ferguson et al. (2018) provides an enlarged list of pastoral invertebrate pests, with 'total estimated annual losses of between $1.7 billion and $2.3 billion in 'average' years' (AgResearch, 2018a). Some of these pests are included in the 2009 report (specifically Clover root weevil and Argentine stem weevil), and Ferguson et al. has provided the basis for updating these species in Table 5. The remaining pests and estimates from the study are shown in Table 7.

Similarly, Saunders et al. (2017) provides an extensive list of invasive weeds and their associated production-loss estimates based upon existing literature. Again, some of these were already included in Table 5, with the remainder presented in Table 7 along with inflation-adjusted loss estimates.

Utilising figures from a cost benefit analysis of Wilding Pine Management Programme Phase 2 (Sapere, 2018) produces an estimate for surrendered agricultural production due to wilding conifers of $3 million in 2019-20.

Latham et al. (2020) conducted a review of the damage to primary production caused by invasive wild mammalian herbivores. While they estimated deer and wallaby damage at an affected farm level, the absence of robust population spread and density data prohibited national level estimates. Similarly, Bengsen, West and Krull (2017 p.329) noted that "the economic impact of pigs in New Zealand has also had little attention".

In the period since 2009, some invasive species, such as the Great White butterfly, have been eradicated (DOC, 2016). For some newer incursions, such as velvetleaf, the impacts on pasture, crops and livestock are currently unknown (AgPest, 2021), although containment and eradication measures appear to be succeeding (Horizons, 2021). The oyster parasite, *Bonamia ostreae,* is another example of new incursion with unknown impact (Lane et al., 2016), with initial identification in farmed oysters resulting in the disposal of all flat-oyster stocks in 2017, however its presence has now been detected in wild oyster populations of the Foveaux Strait (MPI, 2021a).

Table 7. Additional invasive species and associated annual production losses 2019-20 ($'m)

Species	**Reference**	**2019-20**
Animal		
Deer	(Latham et al., 2020)	Not known[10]
Wallabies	(Latham et al., 2020)	Not known[11]
Pigs	(Bengsen, West, and Krull, 2017)	Not known[12]
Insect/invertebrate		
Grass Grub	(Ferguson et al., 2018)	400
Black beetle	(Ferguson et al., 2018)	203
Porina	(Ferguson et al., 2018)	72
Nematodes	(Ferguson et al., 2018)	600
Slugs	(Ferguson et al., 2018)	228
Plant		
Scotch Broom	(Saunders et al. 2017)	9
Chilean needle grass	(Saunders et al. 2017)	0
Sweet brier	(Saunders et al. 2017)	8
Hieracium	(Saunders et al. 2017)	6
Yellow bristle grass	(Saunders et al. 2017)	280
Nassella tussock	(Saunders et al. 2017)	29
Other arable weeds	(Saunders et al. 2017)	20
Wilding conifers	(Sapere, 2018)	3
Velvet Leaf	(AgPest, 2021)	Not known[13]
Total (GST Inclusive)		**1,858**

[10] Unable to estimate output losses due to absence of robust population spread and density data.

[11] Unable to estimate output losses due to absence of robust population spread and density data.

[12] Unable to estimate output losses due to absence of economic and population data.

[13] Relatively new incursion with unknown impact on pasture, crops and livestock.

5.3 Community expenditures

Comparing the value of herbicide and pesticide imports between 2008-09 and 2019-20 provides another proxy for assessing changes in defensive expenditure. The use of this import data is however largely illustrative, as herbicide and pesticide costs have already been captured in defensive expenditure of Regional Councils, central government and farmers in previous tables.

In 2019-20, over $308 million of herbicides and pesticides were imported into New Zealand. This is a 19 percent increase from 2008-09 (adjusted for inflation). Interestingly, imports from Australia, China and South East Asia have all increased, while imports from Europe and the United States have fallen. This could be the result of patents expiring, shifting production facilities, and the established use of generic rather than novel actives. While an increase in the value of herbicide imports reflects increased use[14], these values have not been included in the total costs because changes in crop types and cropping practices (e.g., pre-harvest spraying of cereal crops to improve uniformity of seed moisture) and land use change or development (e.g., increase in viticulture area) may be affecting the values.

Table 8. Imports of herbicides, insecticides, rodenticide and fungicides 2019-20 vs 2008-09 (HS code 3808) ($'m)

	2019-20	2008-09 in 2020 dollars	% Change
Imports (cost including insurance and freight, CIF)	308.1	258.9	19%

Source: Stats NZ Infoshare

[14] Import volumes are not available at 4-digit HS code level hence volume trend analysis is not possible.

6 Total economic cost

6.1 Total defensive expenditure

Table 9 presents total Regional Council, central government and private sector expenditure as a proxy for New Zealand's defensive expenditure on pests and weeds. With the inclusion of GST, total defensive expenditure is estimated to be almost $1.7 billion in the 2019-20 financial year. This represents a total increase of 44 percent compared to 2009 (inflation adjusted) levels.

As a percentage of GDP ($314 billion at June 2020; Stats NZ, 2020), defensive expenditure has remained fairly stable from 0.55 percent in 2009 to 0.54 percent in 2020 despite the primary sector's declining share of total GDP from 5.61 percent in 2009 to 5.24 percent in 2020.

Table 9. Total defensive expenditure on pests and weeds 2019-20 vs 2008-09 ($'m)

		2019-20	2009 estimates in 2020 dollars	% Change
Regional Councils				
	Total (Table 1)	75.6	44.7	69%
Central Government				
	2009 Equivalence (Table 3)	590.5	507.0	16%
	2020 Additional (Table 6)	240.4		
	Total	830.9	507.0	64%
Private Sector				
	2009 Equivalence (Table 4)	504.5	493.5	2%
	2020 Additional (Table 6)	51.7		
	Total	556.2	493.5	13%
Total (GST exclusive)		1,462.7	1,045.2	40%
Total (GST inclusive)		1,682.1	1,175.8	43%

	2020	2008	Difference
Defensive expenditure as a % of GDP	0.54%	0.55%	-0.01%

6.2 Defensive expenditure and primary industries GDP

Comparing equivalent defensive expenditure from 2009 and 2020 shows that, as a percentage of primary industries GDP, defensive expenditure has fallen to 7.5 percent. This analysis compares only equivalent expenditures, and so excludes the additional items that have arisen since 2009 and are recorded in Table 6.

With the significant financial response to *M. Bovis* excluded, central government defensive expenditure has decreased from 4.4 to 3.8 percent of primary sector GDP. Regional council expenditure has proportionately increased, however much of this increased spend can be attributed to 'Predator Free' initiatives.

Proportionately, private sector expenditure has also decreased; however this is likely to be significantly influenced by productivity gains in the dairy sub-sector. Dairy herd/farm productivity has increased significantly since 2009 (increasing from 123,043kgms to 169,595kgms per herd), while dairy farm pest and weed expenses have remained constant. While dairy has contributed the most to the primary industries' overall GDP growth, it does not contribute significantly to overall pest and weed expenditure (potentially a function of farming on better cultivated, more intensively farmed land, with sheep and beef farming conducted on more marginal land with higher pest and weed loads). Combined with OSPRI's lower required spend on TB control, this is an underlying cause of private sector expenditure decreasing as a percentage of primary industry GDP.

Table 10. Comparison of equivalent defensive expenditure and primary sector GDP 2019-20 vs 2008-09

	2019-20	**2008-09**	**% Change**
Primary sector GDP in 2009-10[15] dollars ($'m)	13,345	10,912	22%
			Difference
Regional council	0.6%	0.4%	0.2%
Central government	3.8%	4.4%	-0.6%
Private sector expenditure	3.2%	4.3%	-1.1%
Total Defensive Expenditure as % of primary sector GDP	**7.5%**	**9.0%**	**-1.5%**

[15] Statistics NZ's longitudinal GDP by industry data is presented in 2009-10 dollars. As such, expenditure from 2008-09 and 2019-20 was converted into 2009-10 dollars in the working to allow comparison with primary industries GDP (combined agriculture, forestry and fisheries GDP figures).

6.3 Total cost of pests and weeds

The total economic cost of pests to New Zealand's primary sector is estimated to be almost $6 billion in the 2019-20 financial year (Table 11). This represents a 118 percent increase on the 2009 estimate (adjusted for inflation). This is significantly driven by the inclusion of more invasive species, and a significantly higher estimate for losses associated with Californian thistle (See Appendix 3).

Of the $6 billion estimate, defensive costs represent almost $1.7 billion (28 percent), and production losses $4.3 billion (72 percent). This is a different balance from the 2009 report which had defensive costs at 43 percent, and production losses at 57 percent. This results from greater impact of pests arising from higher primary sector production value and the availability of estimates for more invasive species. The increase in primary production value is driven in part by higher commodity prices rising by an average 47 percent since 2009[16].

Table 11. Total economic cost of pests in New Zealand 2019-20 vs 2008-09 ($'m)

Area of impact	2019-20	2009 estimates in 2020 dollars	% Change
Defensive Expenditure (incl. GST) (Table 9)	1,682.1	1,175.8	43%
Production losses (incl. GST) (Table 5 and 7)	4,290.6	1,568.4	174%
Total Economic Value	**5,972.7**	**2,744.3**	**118%**

[16] ANZ Commodity Price Index June 2020 vs June 2009 shows increases ranging from 5% for horticultural products to 78% for meat and wool.

6.4 Multiplier effects of production losses

As with Nimmo-Bell (2009), a multiplier has been applied to the production losses to account for the upstream and downstream impacts of pests on primary sector output on GDP and employment. As noted in the 2009 report, the multiplier effect indicates the relationship between some observed change in the economy and the amount of economic activity that this change creates throughout the economy. In this case, a multiplier is used to assess the flow on effects caused by a reduction in primary sector revenue due to the production losses caused by invasive pests.

Nimmo-Bell (2009) applied a multiplier of 1.9, noting that a multiplier of 2.5 to 2.9 had been observed in the early 1990s but that the multiplier effect had been decreasing since the late 1970s due to continued on-farm factor productivity improvements. This report applies a multiplier of 1.741[17], and is consistent with the decreasing multiplier trend.

Applying this multiplier brings the total economic cost of defensive expenditure and production losses to over $9.1 billion in 2019-20 (Table 12). This is 2.9 percent of GDP, a significant increase from the 1.9 percent recorded in the 2009 report and despite the primary sector's shrinking share of total GDP. This increase has been driven primarily by the inclusion of production losses from additional invasive species and an increase in the value of primary sector output.

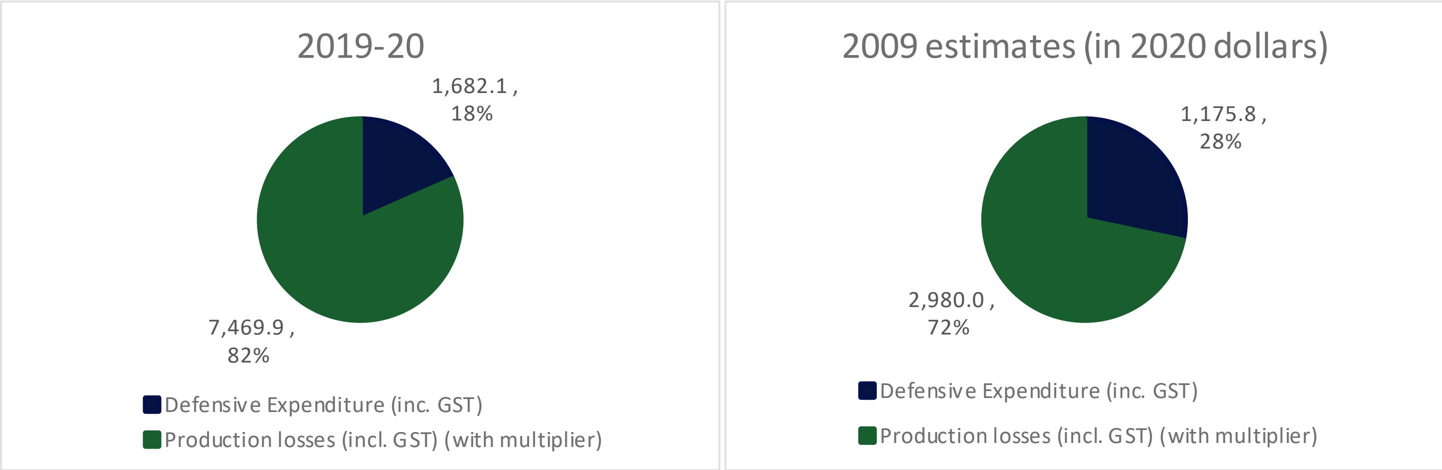
Table 12. Total economic cost of pests to New Zealand including multipliers 2019-20 vs 2008-09 ($'m)

Area of impact	2019-20	2009 estimates in 2020 dollars	% Change
Defensive Expenditure (inc. GST)	1,682.1	1,175.8	43%
Production losses (incl. GST) (with multiplier)	7,469.9	2,980.0	151%
Total Economic Value (incl. GST) (with multiplier)	**9,152.0**	**4,155.8**	**120%**
Multiplier used	1.741	1.9	

Production losses now account for 82 percent of the $9.1 billion total economic cost, up from 72 percent in 2009 (adjusted) (Figure 1). Conversely, defensive expenditure has fallen as a proportion, down from 28 percent in 2009 (adjusted) to 18 percent in 2019-20.

[17] Sourced from the interim input-output model of the CBA framework from *M. bovis*: Measuring Economic Impacts of Biological Incursions (Nimmo-Bell and Market Economics, June 2021).

Figure 1. Proportions of defensive expenditure and production losses in the total economic cost of pests in New Zealand 2019-20 vs 2008-09 ($'m)



7 Conclusion

While like-for-like biosecurity spend has declined as a percentage of primary sector GDP since 2009, biosecurity incursions have led to new spending, resulting in defensive expenditure expanding to 10.8 percent of primary sector GDP from 9.0 percent in 2009. With the growing value of primary sector output coupled with additional invasive species, production losses, inclusive of multiplier effects, has been magnified, rising by 151 percent and accounting for a larger 82 percent share of total economic cost of pests. This implies greater benefits in biosecurity investment to control pests.

To assess the net economic benefit of biosecurity investment for a specific pest among policy options of do nothing, control, and eradication among others, a decision support tool is needed such as the CBA framework under development from the research project '*M. bovis*: Measuring Economic Impacts of Biological Incursions'. This decision support tool combines on-farm impact with epidemiological modelling to result in national sector impact, then expands to wider economic impact and considers non-market impact (e.g. environmental, social, cultural) with Multi-Criteria Analysis.

Gaps in studies, such as prevalence data and robust impact assessments inhibit accurate estimation of production losses for a number of mammalian pests, such as deer, wallabies, pigs, but also rabbits (where estimation in this report used 30-year-old model). This is critical in cost benefit analysis to justify and/or prioritise biosecurity investment. The discontinuation of farm monitoring reports has prevented capture of defensive expenditures for some industries, particularly the vegetable sub-sector, which accounted for 11 percent of private sector expenditures in 2009. The lack of comprehensive data of industry contribution to GIA funding and resulting expenditures may have underestimated private sector defensive expenditures.

Government funding and expenditure now also consists of a web of different initiatives and programmes, with previous business-as-usual expenditure blended with new investment (an example being the Predator Free programme). Science funding, in particular, is difficult to untangle, with differing bodies (MPI, MBIE) providing funding through differing mechanisms (Science Challenges, Sustainable Food and Fibre Fund), to differing research bodies who work collaboratively but record expenditure differently.

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Appendix 1 – On-farm defensive cost calculations

Sector	Cost ($'m)	Calculation
Dairy	59.2	11,179 farms (herds) at $5,299 per herd (owner-operator, as this captures whole farm costs) (Dairy NZ, 2019)
Sheep, Beef and Deer	115.4	9165 farms at $19,290 per farm, less arable costs (below) (BLNZ, 2021)
Arable	61.4	465 farms at $132,000 per farm (using BLNZ Class 8 farms - SI Mixed finishing; with cropping equating to 70% of revenue, as a proxy per ANZ, 2013) (BLNZ, 2021)
Pipfruit	30.8	Hawkes Bay 4746 ha at $3,500 per ha, Nelson 2400 ha at $3,700 per ha, and Rest of New Zealand 1469ha at $3,600 per ha. (MPI, 2019)
Viticulture	45.1	39,935 ha at $1130 per ha (NZ Wine/MPI, 2020)
Kiwifruit (excluding Psa additional costs)	28.4	12,900 ha (MPI, 2020a) at pre-Psa cost of $1300 per ha (in 2013) adjusted to 2020 dollars. (ANZ, 2019)
Vegetables	49.4	Nimmo-Bell, 2009, estimate adjusted for inflation into 2020 dollars.
OSPRI (TB Control)	55.1	Pest control and management, $38.3m + Disease management and testing, $16.9m (OSPRI, 2020)
Household	57.6	1.697m households at an annual estimated expenditure of $34 per household (2009 estimate adjusted for inflation)
Additional (Table 7)		
Apiary	14.3	869,056 hives at Varroa treatment of $14-19 per hive (MPI, 2020b)
Kiwifruit (expenses due to Psa)	10.1	12,900 hectares (MPI, 2020) at $2200 per hec (ANZ, 2019) *less* Kiwifruit (excluding Psa additional costs) (above)
OSPRI (NAIT/other)	22.6	All expenses, $77.8m, less Pest control and management, $38.3m and Disease management and testing, $16.9m (OSPRI, 2020)

Kiwifruit Vine Health	3.7	183m trays at PSA levy of 0.6c per tray and Biosecurity Readiness levy of 1 and 4/10th cents per tray (NZKGI, 2018)

Appendix 2 – Production losses: Adjustment assumptions and recalculations

Species	Direction of change since 2009			Assumptions and calculations
Animals				
Possums – Bovine TB	Prevalence / impact change	Production / value change	Overall change	In a 2014 survey (UMR 2014), farmers who had experienced TB in their herds were asked to estimate their overall financial cost. A weighted average from this survey provides an average estimated cost of $68,350 per herd. A similar methodology was used to estimate an average duration of infection of 2.48 years. Utilizing these two figures provides an estimated average loss of $27,532 per infected herd per year (in 2014 dollars). The prevalence of TB infected herds has fallen dramatically over the past decade (and is on track for eradicate by 2026). In December 2020, there were 38 herds (21 beef, 13 dairy and 4 deer) infected with bovine TB (OSPRI, 2021). This compares to near 200 herds in 2009 (and the over 1000 herds in 2000). Since 2014, sheep/beef/deer farm gross revenue have increased by 27% (BLNZ, 2021). For dairy, the 2013-14 payout was at an all-time high of $8.47, and as such gross farm revenue was 12% lower in the 2019-20 season compared to 2012-14 (Dairy NZ, 2020). Adjusting the 2014 estimated loss per herd ($27,532) by the changes in sector gross revenue, provides a calculation of (25 herds x $27,532 per herd x (1+.27))+(13 herds x $27,532 x (1-.12)) = $1.2m per year.
	↓	↑	↓	

				Applying a similar methodology to 2009 data gives a calculation of 200 herds x $24,334 per herd = $4.8m per year; comparable to the figure of $4.5m quoted in Nimmo-Bell (2009).
Possums – Forestry	Prevalence / impact change	Production / value change	Overall change	Nimmo-Bell (2009) stated an overall loss of production due to possums of $40m. This figure was referenced from Bertram (1999) which in turn referenced Cowan (1996). Of this $40m, $4.5m were losses associated with bovine TB, with the remainder being losses to forestry production. Since 2009, the area of exotic forest has decreased from approximately 1.9m hectares to 1.84m (a reduction of 3.2%). Across the same timeframe, log prices have increased by an estimated 47% (MPI, 2020c; estimated due to changes in how log price averages were calculated since 2017). A change in possum numbers between 2009 and 2020 is difficult to come by, and is assumed as a reduction of 25%. Starting with the $40m from Nimmo-Bell (2009) and applying the changes outlined above provides a calculation of ($40m – $4.5m) x (1 - 3.2%) x (1 + 47%) x (1 – 25%) = $37.9m lost production in 2020.
	⬇	⬆	–	

	Prevalence / impact change	Production / value change	Overall change	
Rabbits	↑	↑	↑	The methodology used in Nimmo-Bell's (2009) came from Bertram (1999). Bertram (1999) originally estimated that 2 million sheep were displaced in high rabbit prone areas, at a cost of $25 per head, totalling a production loss of $50m (in 1999 dollars). Nimmo-Bell reassessed these figures, reducing the number of displaced sheep to 1 million (based upon estimates of a 50% reduction in rabbit populations following the release of Rabbit Haemorrhagic Disease, RHD), a value of $50 per head (based on IRD values), which equated to a production loss of $50m (in 2008 dollars). While RHD had significantly reduced rabbit populations by 2009, surviving populations have become increasingly resistant to the disease (ORC, 2019). Rabbit populations are capable of rebounding quickly from natural disasters or control pressures, and reports indicate that the rabbit population in the prone areas of Otago and South Canterbury are "as bad as they've ever been" (TVNZ, 2020). IRD (2019) values a hogget at $130, a figure that is also the average value across all sheep classes in BLNZ's South Island High Country farm survey (BLNZ, 2021). Assuming rabbit numbers have rebounded, and now displace 1.5 million sheep (75% of 1999 levels), following the same calculation methodology as Bertram (1999) and Nimmo-Bell (2009), rabbits accounted for losses of 1.5m displaced sheep x $130 per head = $195m lost production in 2020.

Birds – viticulture	Prevalence / impact change ↓	Production / value change ↑	Overall change ↑	Nimmo-Bell (2009) based its $9.7m estimate on a 3% loss in grape production due to birds (despite existing bird control efforts) (Boyce et al. 1999). A more recent study, (Kross et al. 2012) found similar levels of grape losses from birds; 2.4% for Sauvignon Blanc and 3.4% for Pinot Noir. The purpose of Kross et al. (2012) was to investigate the benefit of having native falcons present in a vineyard (to reduce bird numbers and grape damage). In vineyards with falcons, losses due to birds fell to 0.8% in Sauvignon Blanc and 1.1% of the Pinot Noir vineyards. Wineries in Marlborough and Wairarapa now have active programs to support the introduction of falcons (NZ Wine, 2016). Assuming falcons are now active across 25% of vineyard hectarage, reduces bird losses down to 2.5% of total grape production; (75% x 3%) + (25% x 1%) = 2.5%. In 2019, 413,000 tonnes of grapes were harvested in New Zealand, at an average value of $1,890 per tonne (NZ Wine, 2020 p.32). Assuming losses to birds of 2.5%, this equates to 10,590 tonnes of lost grapes, at a valued loss of production of $20 million. ((413,000 tonnes/(1 -2.5%)) – 413,000) x $1,890 = $20m lost production for 2020. The substantive increase from $9.7m in 2009 is driven by a 20% increase in the volume of grapes grown in New Zealand, and an over 50% increase in value of grapes per tonne.

	Prevalence / impact change	Production / value change	Overall change	Nimmo-Bell (2009) referenced a figure of $30m quoted from FAR (2008) (adjusted to $40m in 2020-dollar terms).
Birds -arable	–	↑	↑	The basis of this figure was a 10% loss in production of cereal crops due to birds. Utilizing the same 10% loss figure, along with 2020 production and price data (1.06 million tonnes, at prices between $400-420 tonne, depending on crop type; MPI, 2020a) provides an annual arable cropping production loss due to birds of $40 million in 2020 (see Appendix 1a for full working). It is unclear if 2009 figure was for wheat, barley and oats only, or if maize was also included. It is also unclear if the 10% loss rate also applies to maize (the FAR 2008 report refers to 'cereals'). If maize is included, 2020 production losses were $48m.
Insects				
	Prevalence / impact change	Production / value change	Overall change	Ferguson et al. (2019 p.295) estimates an annual cost of $61m and $174m for dairy and sheep/beef production respectively (in the 2018-19 season). These figures have been left unadjusted for the 2019-20 season, as farm revenues for both dairy and sheep/beef remained relatively unchanged (i.e., a change of less than a percent; for dairy this is based on a 5-year averaged pay-out).
Clover Root Weevil	↓	↑	↓	Biological controls have been successful in significantly reducing the impact of CRW. These controls are estimated to have nearly halved the financial impact of CRW (Ferguson et al. (2018 p.284). "Early in the invasion phase of CRW establishment in New Zealand, it was realised that biocontrol offered the best chance of effective mitigation of the weevil's impact. A search for suitable biocontrol agents culminated in the 2006 introduction and release of an Irish ecotype of a small parthenogenetic parasitic wasp, *Microctonus aethiopoides* Loan (Hymenoptera: Braconidae). Biological

				control of CRW is now well established and suppressing weevil numbers over nearly all of New Zealand" (Ferguson et al., 2018 p.282)
Argentine Stem Weevil	Prevalence / impact change	Production / value change	Overall change	Ferguson et al. (2018 p.295), estimates an annual cost of $100-130m and $60-70m for dairy and sheep/beef production respectively. Midpoints ($115m and $65m) have been taken for this report and left unadjusted (as per Clover root weevil above) While farm production values have increased moderately since 2009, the prevalence and impact of Argentine Stem Weevil has continued to decrease over the past decade. "Once considered the foremost invertebrate pastoral pest in New Zealand, the impacts of ASW were reduced considerably through a combination of using animal friendly endophyte-infected ryegrasses and the establishment in the early 1990s of the biocontrol agent *Microctonus hyperodae* providing an example of integrated pest management" (Ferguson et al., 2018 p.280)
	↓	↑	↓	
Varroa mite	Prevalence / impact change	Production / value change	Overall change	Since 2009, research has found that some hives have developed defence mechanisms and resistance to Varroa (Mondet et al., 2021). There has however been a near quadrupling of honey values since the 2009 report (which quoted a loss estimate of $18m), with export values increasing from $11.66kg to $41.28kg in 2020. Landcare Research (2020) estimates that 30,711 colonies were lost to varroa in 2020. The average hive produced 31.1kg of honey, with an average export value of $41.28/kg (MPI, 2020b). Using these figures results in loss of honey production value in 2020 of 30,711 hives x 31.1 kg/hive x $41.28/kg = $39.4 million.
	↓	↑	↑	

Rose grain aphid	Prevalence / impact change	Production / value change	Overall change	Rose grain aphids are the vector for Barley Yellow Dwarf Virus (YDV). Nimmo-Bell (2009) recorded a production loss of $12m, which was an adjusted for inflation reference from Bertram (1999). This in turn was a midpoint figure from Grundy's (1990) estimate of $1m - $20m. van Toor et al. (2016) found that grower practices, including timing sowing with low aphid activity, and the select use of seed and foliar insecticide applications, has the effect of lowering the incidence of YDV. In normal years, losses in untreated crops were 5.2%, while losses in crops that used foliar insecticide fell to 1-2%, and in crops that used both seed and foliar insecticide losses fell to less than 1%. The 5% loss on untreated crops is similar to that loss figure originally used in Grundy (1990; and subsequently Bertram, 1999, and Nimmo-Bell, 2009). With improved management practices since 1990, these figures indicate that since Grundy's original research losses from YDV have decreased substantially, potentially by at least half. The presence of aphids in 2019 was consistent with those reported in previous years (FAR, 2019), indicating that production loss should have been in line with a typical year and those observed by van Toor et al. (2016). Grain prices have remained relatively constant since 2009, and currently sit 9.6% higher in Q4 2020, than they were in Q4 2009 (Stats NZ Producers Price Index, 2020). Working from the Nimmo-Bell (2009) reported figure of $12m, reducing the loss impact of YDV by half to account for modern practices, and allowing for a 9.6% increase in grain values, provides a loss in production estimate of $12m x 50% x (1 + 9.6%) = $6.6 million
	↓	↑	↓	

Lucerne weevil	Prevalence / impact change	Production / value change	Overall change	Nimmo-Bell (2009) mistakenly attributed the $7m from Goldons et al. (2005) to Lucerne aphids rather than the Lucerne weevil. While anecdotally "the on-farm use of lucerne (Medicago sativa) for grazing and conserved feed has increased in New Zealand over recent years" (Harvey et al. 2014 p.111), there are no available statistics to quantify this increase. Given the lack of additional data to work from, the 2009 figure has been adjusted for inflation to $9.6 million in 2020 dollars.
	N/A	N/A	N/A	
Wasps	Prevalence / impact change	Production / value change	Overall change	Bertram (1999) assumed a 2% reduction in honey production due to wasps, calculated in 1999 to be $50 million x 2% = $1 million. Nimmo-Bell (2009) applied the same methodology, observing a doubling in the value of honey production between 1999 and 2009, resulting in a $2 million loss. Honey production and value has grown substantially over the last decade, with exports of $425 million in 2020 (MPI, 2020b). Applying the same 2% loss rate equates to $8.5 million in production losses. Alternatively, it is estimated that 6,581 hives were lost to wasps in 2020 (Landcare Research, 2020). Applying the same methodology as used previously for varroa mites, provides a loss in honey production value of 6,581 hives x 31.1 kg/hive x $41.28 kg = $8.4 million, very similar to the figure calculated using Bertram's (1999) methodology.
	N/A	↑	↑	

	Prevalence / impact change	Production / value change	Overall change	Since 2009 there have been a number of factors influencing the overall production losses.
Gum Leaf Skeletoniser	↑ ↓	↑	↑	The 5-year log price average has increased by an estimated 52% (MPI, 2020). The Gum Leaf Skelentoniser has now also spread from Auckland and Hawkes Bay into the key forestry regions of South Waikato and wider Bay of Plenty (Forestry Health News, 2014). At the same time, a biological control has been introduced (the parasitoid *Cotesia urabae*) which appears to be having a significant impact upon Gum Leaf Skeletoniser numbers (up to 40% reduction in some regions; Forestry Health New, 2016). Working from the $13 million loss in Nimmo-Bell (2009) and applying an assumed doubling (+100%) in the forestry area effected, a 25% reduction in impact due to the biological control, and a 47% increase in log prices provides a calculation of $13m x (1+100%) x (1- 25%) x (1+47%) = $31 million.

Plants				
Giant buttercup	Prevalence / impact change	Production / value change	Overall change	Nimmo-Bell (2009) referenced an adjusted figure of $177m from Bourdot (2003).
	–	↑	↑	Recalculating the Bourdot (2003) model using 2019-20 dairy production data and a 5-year averaged payout ($6.38 kgms) provides an estimated loss in production of $223m (see Appendix 1b). As prevalence and impact were assumed to remain constant from the 2003 model, the change in loss estimate is driven entirely by increases in dairy production and payout.
Californian Thistle	Prevalence / impact change	Production / value change	Overall change	Nimmo-Bell (2009) referenced Bertram (1999) and an undisclosed Lincoln University study, both of which provide an estimation of production losses on Otago and Southland sheep farms only amounting to $26m in 2009. Bourdot et al., (2016 p.189) makes a national estimation across three farm types (dairy, sheep and beef, deer) based upon annual pasture and dry matter losses caused by Californian thistle. This estimate has been recalculated in Appendix 1c using 2019-20 season data (providing a 2020 estimate of $722m). This is a significant increase on previous estimations. As Saunders et al. (2017) notes when referencing Bourdot et al., (2016); "The authors (Bourdot et al., 2016) noted that the results of this analysis suggested that the estimate of $1.2 billion as the total cost of pastoral weeds to New Zealand (Bourdot et al., 2007) was likely to be an underestimate, since the estimated costs of Californian thistle alone constituted approximately 50% of that total" (p.384).
	↑ Change due to methodology	↑ Change due to methodology	↑ Change due to methodology	

Gorse	Prevalence / impact change	Production / value change	Overall change	Nimmo-Bell (2009) referenced Williams and Timmins (2002), whose estimation concerned only the impact of gorse on forestry production ($38m in 2020 dollars). Saunders et al. (2017) provides a total annual estimate to pastoral activities for both production losses and defensive costs of $72.3m (adjusted to $78m in 2020 dollars). Assuming a 50:50 split between production losses and defensive costs, provides an estimate of $39m Based upon these two figures, a total estimate of $76m has been made for forestry and pastoral production losses
	↑ Change due to methodology	↑ Change due to methodology	↑ Change due to methodology	
Blackberry	Prevalence / impact change	Production / value change	Overall change	Saunders et al. (2017) provides a total annual estimate for both production losses and defensive costs of $14.3m (adjusted to $15.2m in 2020 dollars). It is assumed that production losses account for half this figure, and equate to $7.6m. Adjusting Nimmo-Bell (2009) for inflation provides a comparable estimate of $7.1m (in 2020 dollars).
	–	–	–	
Forestry weeds	Prevalence / impact change	Production / value change	Overall change	Saunders et al. (2017) estimates annual forestry sector lost production due to weeds at $334m, based upon Scion research (adjusted to $361m in 2020 dollars). The increase from $214m in Nimmo-Bell (2009) could largely be explained by the estimated 47% increase in log prices since 2009.
	–	↑	↑	

	Prevalence / impact change	Production / value change	Overall change	
Powdery mildew	–	↓	↓	Bayer Crop Science New Zealand (2021) lists four different types of "Powdery mildew"; *Podospara leucotricha* in apples, *Erysiphe betae* in beet, *Blumeria graminis* in wheat, and *Erysiphe necator* in grapes, all of which are classified as fungal diseases. Bertram (1999), referenced in Nimmo-Bell (2009), referred only to losses in peas, and was based upon the grossing up of field trial results in 1993. Since 2009, pea production was increased from 59,000 tonnes to approximately 70,300 tonnes (Hort NZ, 2009 and 2019). However, over the same period export values have decreased from $135.3m to $121.5m, a 10% reduction (calculated to be $2,293/t in 2009, down to $1,728/t in 2019). Applying this 10% reduction in value to the $9 million calculated in Nimmo-Bell (2009) equates to $8.1 million in 2020.

Aquaculture/waterways/marine				
Pest	Prevalence / impact change	Production / value change	Overall change	
Didymo (*Didymosphenia geminate*)	↓	↓	↓	Since 2009, there is increased understanding of the spread and impact of *Didymosphenia geminate*. The spread of Didymo has largely been contained to South Island alpine rivers, thought to be due to low p and n levels in these rivers. (NIWA, 2014). There is thought to be minimal impact to agricultural production, (and so an estimate of $1m has been made, down from $24m in 2009) with a much more significant impact being on ecology, recreation, tourism.
Sea squirt (*Styela clava*)	N/A	N/A	N/A	The estimate of $15m provided in Nimmo-Bell (2009) was based upon an early projection by NZIER, (2005) following the first reports of *Styela clava* in Auckland, 2005. The revised annual estimate of $7m (2020) is based upon a deconstruction of the net present value of $26.4m (over 24 years) in Soliman and Inglis (2018).
Didemnum veillum	–	–	–	No change has been made to the estimate made in Nimmo-Bell (2009) other than an adjustment for inflation. This was based upon the research of Fletcher et al. (2013), which found "no direct effects of *Didemnum veillum* fouling on mussel size and condition, but did indicate negative effects on the destiny of small mussels" (p.27).

Appendix 2a – Calculation of arable and grape production losses due to birds, 2020

	Loss rate	10%				
	Actual production (t)	Est. production without losses (t)	Lost production (t)	Price (per t)	Lost production ($)	
Milling wheat	112,805	125,339	12,534	420	$	5,264,233
Feed wheat	369,258	410,287	41,029	400	$	16,411,467
Malting barley	91,225	101,361	10,136	420	$	4,257,167
Feed barley	289,680	321,867	32,187	400	$	12,874,667
Milling oats	10,702	11,891	1,189	410	$	487,536
Feed oats	8,168	9,076	908	400	$	363,022
	881,838	**979,820**	**97,982**	**405**	**$**	**39,658,091**
Maize grain	181,770	201,967	20,197	420	$	8,482,600
	1,063,608	**1,181,787**	**118,179**	**407**	**$**	**48,140,691**

Sources: MPI, 2020a

	Loss rate	2.5%				
	Actual production (t)	Est. production without losses (t)	Lost production (t)	Price (per t)	Lost production ($)	
Grapes	413,000	423,589.74	10,590	1,890	**$**	**20,014,615**

Source: Wine NZ, 2020

Appendix 2b – Recalcuation of Bourdot et al., 2003 (p.299), production losses due to *Ranunculus acris* (Giant buttercup), using 2019-20 season data

	Number of cows	Milk solids per cow (kg)	Milk solids total (million kg)	Value of dairy production ($ million)	% area infested	% loss in revenue	Revenue loss ($ million)
Region							
Waikato	1,104,097	364	401.9	2,562	5	1.7	44.3
Hawkes Bay	45,516	347	15.8	101	10	3.3	3.4
Taranaki	467,761	396	185.2	1,181	35	11.6	155.0
District							
South Wairarapa	34,610	378	13.1	83	10	3.3	2.8
Horowhenua	45,142	400	18.1	115	10	3.3	3.9
Tasman	54,081	353	19.1	122	30	10	13.5
Lost production				**4,164**			**223.0**

Source: Dairy NZ, 2020

Appendix 2c – Recalculation of Bourdot et al., 2016 (p.189), production losses due to *Cirsium arvense* (Californian thistle), using 2019-20 season data

	Dairy (a)	Dairy (b)	Dairy average	Sheep/Beef	Deer	Total*
Milking cows	4,921,548					
Milksolids per cow	385					
$ per kgms	6.4					
Revenue per farm		1,166,413		623,000		
Venison tonne produced					16,733,000	
$ per kg venison					11	
Number of farms		11,179		9,165		
Gross Revenue ($ million)	$12,081	$13,039	$12,560	$5,710	$178	
Mean annual pasture loss	3.6%	3.6%	3.6%	4.1%	3.9%	
Lost production ($ million)	**$451**	**$487**	**$469**	**$246**	**$7**	**$722**

Sources: Dairy NZ, 2020, BLNZ, 2021 and DINZ, 2018

* Total of Dairy average, Sheep/Beef and Deer

Appendix 3 – Changes in production losses due to pests, 2009 vs 2020

	2009 report		2021 report		
	Annual losses in 2008 dollars ($'m)	Annual losses in 2020 dollars ($'m)	Annual losses in 2020 dollars ($'m)	Difference in 2020 dollars ($'m)	Percentage change
Animal					
Possums	52	63	39	-24	-38%
Rabbits	50	61	195	134	22%
Birds - viticulture	10	12	20	8	65%
Birds - arable	33	39	40	1	1%
Insect/invertebrate					
Clover root weevil	312	378	235	-143	-38%
Argentine stem weevil	160	194	180	-14%	7%%
Varroa mite	15	18	39	21	117%
Rose grain aphid	12	15	7	-8	-55%
Lucerne weevil	8	10	1	0	0%
Wasps	2	2	8	6	249%
Gum leaf skeletoniser	13	16	31	15	94%

Plant					
Giant buttercup	177	214	252	37	17%
Californian Thistle	26	31	751	720	2286%
Gorse	31	38	76	38	102%
Blackberry	6	7	8	0	4%
Forestry	214	259	361	102	39%
Powdery mildew	9	11	8	-3	-26%
Aqua/waterways/marine					
Didymo	24	29	1	-28	-97%
Sea squirt	15	18	7	-11	-61%
Didemnum vexillum	1	1	1	0	0%
Total	**1,170**	**1,417**	**2,212**	**795**	**56%**