Pieris brassicae (great white butterfly) eradication annual report 2013/14

Craig Phillips, Kerry Brown, Chris Green, Graham Walker, Keith Broome, Richard Toft, Bruce Vander Lee, Michael Shepherd, Simon Bayly and Jo Rees

newzealand.govt.nz

Department of Conservation
Te Papa Atawhai

Cover: Great white butterfly pupa. *Photo: Richard Toft.*

Published by Whakatū/Nelson Office, Department of Conservation, Private Bag 5, Nelson 7042, New Zealand.

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Executive summary

Pieris brassicae, great white butterfly, is a northern hemisphere species that was first detected in New Zealand in Nelson in May 2010. It is a threat to New Zealand native cresses as well as to forage and vegetable brassicas, thus the Department of Conservation (DOC) launched an eradication attempt on 19 November 2012.

Nelson properties infested with *P. brassicae* are detected via inspections conducted by DOC staff and by reports from the public. Nelson residents remain very supportive of the programme and, of the 26,000 properties that are being regularly inspected, difficulty is being experienced accessing only 13 (0.05%).

In the first half of 2014, DOC conducted 54 848 property inspections, which is similar to the 54 656 conducted in all of 2013. The proportion of the *P. brassicae* eggs and larvae present on a property that were found during a DOC inspection was calculated to be in the range 75–95%. The protocol of insecticide-treating all host plants on infested properties then conducting at least one follow-up inspection was estimated to eliminate *P. brassicae* eggs and larvae from >99% of properties that were recognised as infested.

Detection rates (number of infested properties divided by number of inspected properties) declined significantly from 0.035 in 2013 to 0.008 in the first 6 months of 2014. The number of public reports of *P. brassicae* declined from 207 in March–June 2012/13 to 108 in the same period in 2013/14, and the proportion of public reports that was confirmed to involve *P. brassicae* also significantly declined between these two periods.

In 2013/14, the distribution of *P. brassicae* was restricted to the operational area in the vicinity of Nelson city, with the exception of one *P. brassicae* male that was detected in Lud Valley, c. 10 km northeast of the city. Subsequent searches throughout all of Lud Valley detected no additional *P. brassicae*. During autumn 2013/14, *P. brassicae* was detected in 34 of 45 (76%) management blocks.

In the year from July 2013 to June 2014, *P. brassicae* appears to have been contained within the greater Nelson city area where its abundance has significantly declined. Currently, the programme seems on track to meet its goal of eradicating *P. brassicae* from Nelson by 30 June 2015.

Phillips, C.; Brown, K.; Green, C.; Walker, G.; Broome, K.; Toft, R.; Vander Lee, B.; Shepherd, M.; Bayly, S.; Rees, J. 2014: *Pieris brassicae* (great white butterfly) eradication annual report 2013/14. Department of Conservation, Wellington. 37 p.

1. Purpose of this document

This document summarises the Department of Conservation's (DOC) eradication programme for *Pieris brassicae* L. (Lepidoptera: Pieridae), great white butterfly (GWB), to the end of the 2013/14 financial year (July to June). It has been written for senior managers in DOC and the Ministry for Primary Industries (MPI), stakeholders, staff in the *P. brassicae* eradication programme, and people attempting to eradicate other pests. Spring 2014 data are also shown in Appendix 3. Additional information is available from documents listed in the references.

2. Stakeholder contributions and budget

Horticulture NZ contributed $40,000 p.a. to the *P. brassicae* eradication programme in 2012/13 and 2013/14. Dairy NZ provided $10,000 in 2013/14. MPI contributed $27,000 p.a. in 2012/13 and $76,000 in 2013/14 for research to support the eradication attempt. They also forwarded calls received from the public via their 0800 80 99 66 hotline. Plant and Food Research conducted fortnightly surveys at 5–7 Nelson locations outside the eradication zone to monitor for *P. brassicae* and also supplied DOC with *Cotesia glomerata* L. (Hymenoptera: Braconidae) parasites collected from *P. rapae* L. (cabbage white butterfly) for release within the eradication zone. AgResearch co-funded MPI research on *P. brassicae* via its contribution to the Better Border Biosecurity (B3) research collaboration. The TR Ellet Agricultural Research Trust contributed $25,000 in 2013/14 for the data analysis work of Craig Phillips and John Kean (AgResearch).

In the 2013/14 financial year (July to June), DOC spent NZ$1,327,908 (total expenditure = $1,453,908) on the eradication programme, compared with NZ$433,834 (total expenditure = $513,834) in the previous year (Toft 2013). Further details of costs are given in Appendix 1.

3. Background

The natural distribution of *P. brassicae* is Europe and Asia. It was first detected in Nelson on 14 May 2010, has not been recorded elsewhere in New Zealand, is an Unwanted Organism under the Hazardous Substances and New Organisms Act 1996, and is likely to be a pest of forage and vegetable brassica crops. In 2010, MPI responded to monitor and slow the spread of *P. brassicae*. However, DOC advocated for an eradication attempt due to the risk it posed to New Zealand native brassicas—as evidenced by the damage currently caused to native brassicas from *Pieris rapae*—and took over the incursion response to attempt eradication on 19 November 2012. By this time, *P. brassicae* was firmly established in Nelson and spreading (Fig. 1).

New Zealand has 79 native cress species (3% of New Zealand's indigenous flora) of which 55 are currently threatened or at risk of extinction. A further 13 are not currently threatened but are nevertheless at risk from *P. brassicae*. Many of the 68 at-risk species are represented only by small isolated populations; six are profiled in Appendix 2.

Pieris brassicae is deterred by cresses with high glucosinolate levels. New Zealand cresses may contain lower glucosinolate levels than northern hemisphere species, thus could be particularly susceptible. They also face many other threats, including browsing by mammals, habitat destruction and herbivory by *P. rapae*.

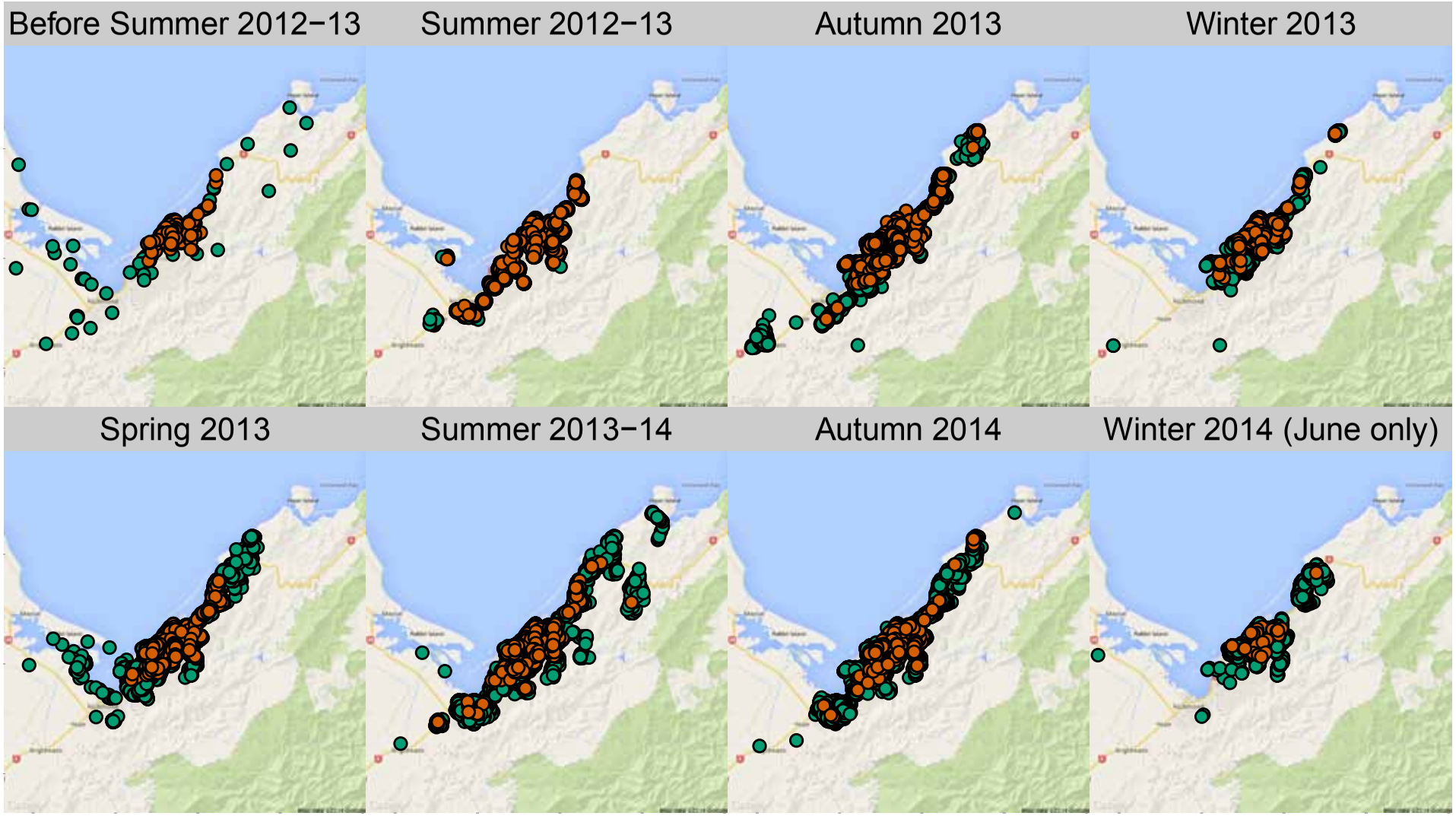

Figure 1. Spatial distribution of *Pieris brassicae* presence (red) and absence (green) records within the Nelson eradication zone from May 2010 to June 2014, split by season, with records from before December 2012 pooled.

Unlike *P. rapae*, which lays single eggs, *P. brassicae* lays eggs in batches of 50–150. The caterpillars feed in groups on a wide range of host plants, and will completely defoliate a plant before crawling >100 m to find another. Late-stage larvae pupate in sheltered locations, often on built structures, and are difficult to find. *Pieris brassicae* adults fly well.

The eradication programme is a world-first attempt to eradicate a butterfly, and is ecologically, socially and technically complex. Effective trapping methods have been crucial to previous invertebrate eradications, but are lacking for *P. brassicae*. Instead, the *P. brassicae* programme depends on searches by DOC staff and reports of sightings by the public. These are facilitated both by the distinctive appearance of *P. brassicae*, and by its occurrence on accessible low-growing plants that are common in home gardens. The programme fosters and receives strong support from local residents. It is based on systematic prioritised searches of the infested area and assiduous management of host plants, which demands excellent staff training, team structure, responsiveness, timeliness, communication and strategy. To assist programme management, DOC divided Nelson into 45 management blocks, which are described in a subsequent section.

Due to the seasonality of *P. brassicae* in Nelson, spring and autumn are the best periods for gauging its abundance and distribution. Thus, comparisons between successive autumns and successive springs provide the most reliable indications of *P. brassicae* population trends. The abundance of *P. brassicae* is monitored by measuring the number of properties infested with *P. brassicae* divided by the number of properties searched, which is here termed 'detection rate'. The distribution of *P. brassicae* is monitored both through searches conducted by DOC staff and by public reports of sightings, which are always validated by DOC. When assessing the distribution of *P. brassicae*, a distinction is drawn between the detections of adults and those of immature stages. The adults are highly mobile and likely to stray beyond the operational area, so their presence beyond this area, though of grave concern, is not regarded as clear evidence of population spread. In contrast, detections of immature stages are more indicative of the presence of a breeding population, and their presence beyond the operational area is regarded as evidence of spread.

3.1 Spatial distribution

Figure 1 shows the spatial distribution of *P. brassicae* presence and absence records within the Nelson eradication zone from May 2010 to June 2014, split by season, with records from before December 2012 pooled. Detections have all been within the greater Nelson city area with four exceptions: In February 2013, passive surveillance detected one parasitised *P. brassicae* larva c. 25 km west of Nelson at Upper Moutere (not shown in Fig. 1), which required intensive work to gain confidence additional *P. brassicae* had not escaped, including increased publicity targeted at Upper Moutere and other coastal areas between Nelson and Motueka. This larva was almost certainly taken to Upper Moutere from Nelson on an infested cabbage. In autumn 2013/14, several *P. brassicae* were found c. 9 km north of Nelson at Glenduan (Fig. 1, 'Autumn 2013/14', northernmost detections), which also required significant follow-up work. One male butterfly was killed in Hope in December 2013, which prompted searches of all properties within a 1 km radius; no further *P. brassicae* were found. In summer 2013/14, a *P. brassicae* male was reported in Lud Valley, c. 10 km northeast of Nelson (Fig. 1, 'Summer 2014/14', easternmost detection). Subsequent searches on all properties along Lud Valley to the coast at Cable Bay detected no further *P. brassicae*. During autumn 2013/14, *P. brassicae* was detected in 34 of 45 (76%) management blocks, which is similar to the figure recorded in autumn 2012/13.

4. Goal, objectives, contingencies and feasibility

4.1 Goal

The programme aims to eradicate *P. brassicae* from Nelson by 30 June 2015, and to confirm that eradication has been successful by 30 June 2017.

4.2 Objectives

For the purpose of setting goals and measuring progress, the process of eradicating *P. brassicae* has been divided into three phases:

1. Contain and suppress the main population ('knock down').
2. Eliminate all remaining sub populations and individuals ('mop up').
3. Confirm success ('surveillance').

In 2013/14, the programme was in the knock down phase. To monitor progress, the transition from knock down to mop up has been defined as when, for an entire spring or autumn, there is no evidence of population spread beyond the operational area, the average detection rate (properties infested divided by properties inspected) across the operational area is ≤0.01, and when zero immature *P. brassicae* are detected in at least half of the management blocks. This last criterion seeks evidence that the population's distribution is becoming increasingly patchy within the operational area.

The programme's current short-term objective is to finish knock down by 30 November 2014.

The programme will have advanced from mop-up to the surveillance phase when zero *P. brassicae* have been detected for an entire spring or autumn. The requirements for gaining high confidence that eradication has been achieved and the surveillance phase can cease are yet to be fully specified, but will involve monitoring, perhaps for 2 years, as defined by statistical modelling.

The programme's current long-term objectives are to finish mop up by 31 May 2015, and to finish surveillance either by 30 June 2017 or by a date defined by statistical analysis as providing high confidence that *P. brassicae* has been eradicated.

4.3 Decision-making triggers

The feasibility and benefit of continuing the eradication programme would be reviewed if:

- Established *P. brassicae* populations are detected outside the Nelson operational area.
- *Pieris brassicae* is clearly expanding its distribution around Nelson.
- *Pieris brassicae* is still present in Nelson by 30 November 2015.
- Despite active searching, *P. brassicae* has not been detected for two consecutive years, or for a period statistically defined as providing high confidence that it has been eradicated.

4.4 Plan for responding to detections beyond Nelson

DOC regularly responds to pest detections in unexpected locations. For example, mice were detected on Maud Island in October 2013, advice was obtained, an eradication attempt was planned, then in July 2014 it was implemented. DOC's procedures for responding to such events are documented in its Island Biosecurity Standard Operating Procedure (olddm-763784) and Island Biosecurity Best Practice Manual (DOCDM-20171). The plan for responding to a detection of *P. brassicae* beyond Nelson follows the same guidelines. Once the Project Leader (Mike Shepherd) and Technical Advisory Group (TAG) Leader (Kerry Brown) are informed of the suspected detection:

- Staff will be directed to confirm the identity of the specimens and obtain all possible information by interview and site visit.
- The Project Leader will keep a written record of all relevant information.
- If the detection is confirmed, then the Conservation Services Manager (Roy Grose) and MPI will be informed.
- The TAG Leader will seek advice from the TAG, then convey that advice to the Project Leader.
- The Project Leader will call for an invasion incident debrief and response planning meeting.
- A response plan will be developed, signed off by the Conservation Services Manager, implemented, then reviewed and reported as necessary.

4.5 Feasibility of eradication and likelihood of success

Phillips et al. (2013a) developed and discussed nine criteria that should be considered when evaluating the feasibility of an eradication attempt:

1. Irrespective of its density, the population can be forced to decline from one year to the next.
2. Immigration and emigration can be prevented.
3. Every individual must be at risk at some stage of its development.
4. Animals can be detected at low densities.
5. Benefit-cost analysis favours eradication over control.
6. Suitable social, political, legal and institutional environment.
7. Success is favoured by small spatial extent of the population.
8. Environmental impacts of the programme are acceptable.
9. The programme is effectively managed, and its status is reliably monitored and accurately recorded.

A November 2013 assessment of the *P. brassicae* programme considered it was technically feasible with criteria 1 and 2 being marginally met and criteria 3–9 being substantially met (Phillips et al. 2013a). Since November 2013, there has been increasing evidence that criterion 1 is also being substantially met (more details are given in subsequent sections of this report). Thus, eradicating *P. brassicae* appears more feasible now than it did in November 2013.

In October 2013, members of the *P. brassicae* TAG and Dr John Kean (AgResearch) were asked to estimate the likelihood of eradication success to support a cost benefit analysis (East 2013a). Their mean estimate was 56% (range 50–70%). In November 2014, the same people were asked to re-evaluate the likelihood of success based on more recent data, and their mean estimate was 80% (range 70–92%).

5. *Pieris brassicae* life cycle and phenology

After mating, a *P. brassicae* female lays a cluster of 50–150 eggs on a host plant, and can lay a total of about 500 eggs (Gardiner 1963; Spieth & Schwarzer 2001). Measurements of adult longevity range from 1 to 36 days, most often 3–10 (David & Gardiner 1961; Ducatez et al. 2012; Chalil & Kular 2013; Mehrkhou & Sarhozaki 2013). After hatching, larvae feed together and develop through five stages, usually defoliating several host plants in the process. Larvae at the fifth stage crawl away from their host plants to form pupae, typically on vertical surfaces in sheltered locations. Adults develop within their pupal cases and eventually emerge. The time required for *P. brassicae* to complete its lifecycle depends both on temperature (faster when warmer) and day length (some larvae that experience long day lengths at a particular stage of their development in spring form pupae that enter a resting state during summer).

The phenology of *P. brassicae* in Nelson was modelled by Kean & Phillips (2013), and a summary of life stage observations in Nelson from January 2013 to June 2014 is shown in Figure 2; this must be interpreted carefully because pupae are seldom detected relative to eggs, larvae and adults. Most *P. brassicae* life stages occur in Nelson throughout the year, but there are seasonal patterns in the proportions of each life stage present. The following describes the pattern followed by the majority of the population, though exceptions and outliers are always present.

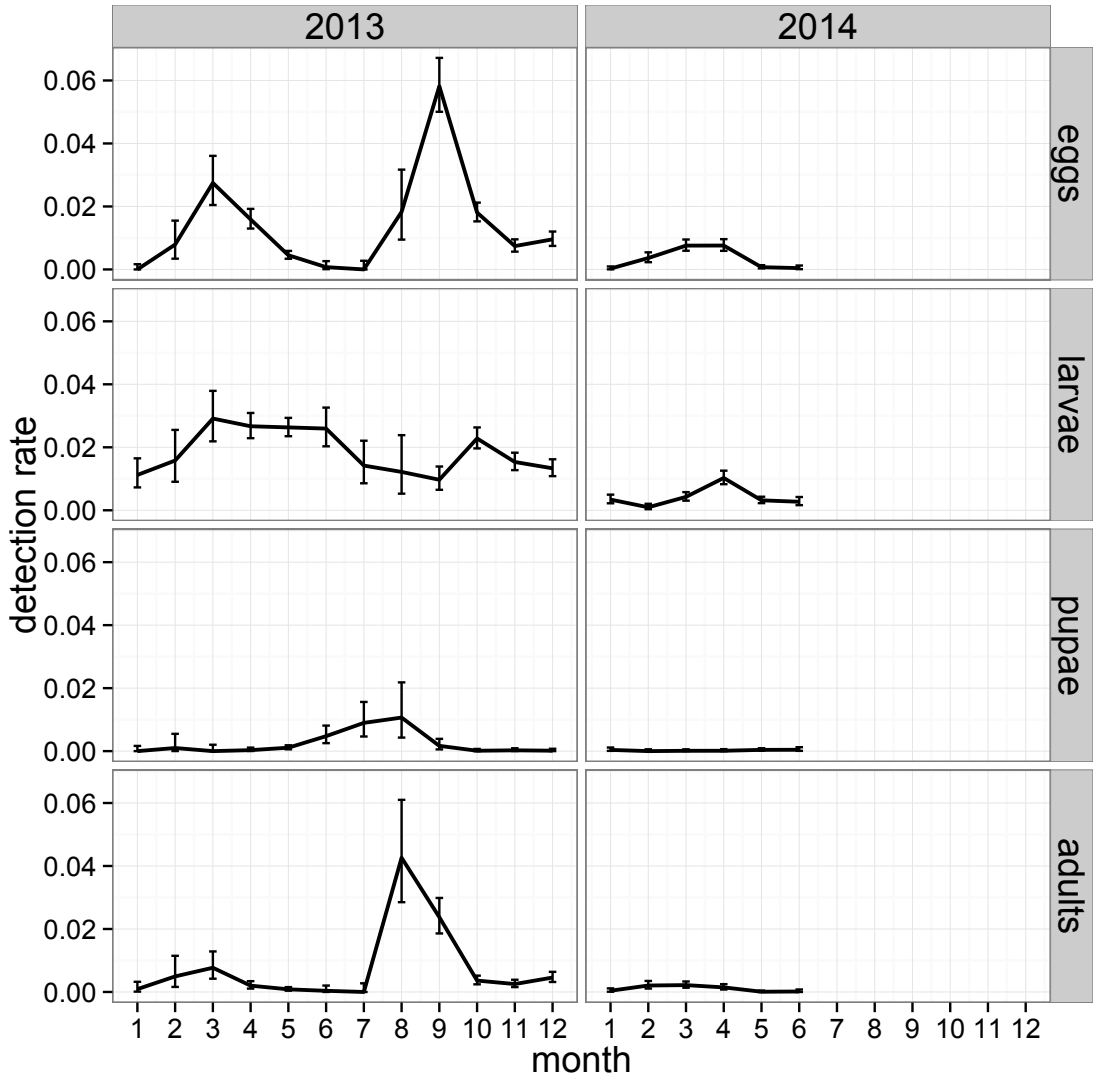

Figure 2. Detection rates from January 2013 to the end of June 2014 for each *Pieris brassicae* life stage. Error bars show 95% confidence intervals.

Most *P. brassicae* reach the pupal stage during winter, there is a flush of adults from mid August to September, and a peak of eggs and larvae during September and October. The first eggs laid in mid to late August reach the pupal stage by early November, with the proportion of *P. brassicae* that are pupae continuing to build up through to December. Around half of these pupae continue to develop, with the earliest reaching the adult stage in December, thus eggs and larvae occur throughout summer. The other half of the pupae present in early summer enter a resting phase (aestivation) and do not reach the adult stage until February–March. Thus, in late summer there is a coincidence of pupae that have been resting since late spring and those that developed from eggs laid during summer. This coincidence culminates in another flush of adults from late February through to April, whose offspring mostly reach the pupal stage by mid winter.

Pieris brassicae pupae are more difficult to detect and treat than the other life stages, and are present in the population in varying proportions throughout much of the year. However, spring and autumn provide key periods of higher vulnerability because most pupae develop to the adult stage during these periods, and adults and their egg and larval offspring are exposed to effective control. Thus, spring and autumn are the two most critical periods for detecting and eliminating *P. brassicae*.

6. Surveillance methods and tactics

Methods for detecting and eliminating *P. brassicae* are constantly being improved. Early refinements were described by Phillips et al. (2013b), and those made subsequently are described in the following sections, along with brief summaries of recent results.

Table 1 provides an overview of the inspections data by year to 30 June 2014. The number of inspections markedly increased following the start of the eradication programme in late 2012. The proportions of sites inspected that were infested declined in 2014 compared with 2013, with every *P. brassicae* life stage being detected at fewer sites. (Data for spring 2014 are given in Appendix 3.)

Four main surveillance methods are used to detect *P. brassicae* in Nelson: Passive, active, general and follow-up. In addition, methods have been developed for capturing *P. brassicae* adults.

Table 1. Sites inspected, sites infested with *Pieris brassicae*, proportion infested (%), and numbers of sites where eggs, larvae, pupae or adults were detected, by year.

YEAR	SITES INSPECTED	SITES INFESTED	DETECTION RATE	SITES WITH EGGS	SITES WITH LARVAE	SITES WITH PUPAE	SITES WITH ADULTS
2010	20	20	1.000	0	15	4	4
2011	84	26	0.310	0	24	1	2
2012	912	288	0.320	17	128	7	12
2013	54 656	1905	0.035	678	1113	57	227
2014 (to 30 June)	54 848	465	0.008	178	231	16	52
Total	110 528	2704	0.024	873	1511	85	297

6.1 General surveillance

General surveillance involves systematically searching a neighbourhood for *P. brassicae*, and is usually a scheduled activity rather than an ad hoc response to a passive surveillance detection.

- 'All-properties-general-surveillance' involves inspecting every property in a neighbourhood.
- 'Garden-only-general-surveillance' involves inspecting only those properties within a neighbourhood known to have gardens.
- 'Host-plant-only-general-surveillance' involves inspecting only those properties within a neighbourhood known to have gardens that contain *P. brassicae* host plants.

During periods when most *P. brassicae* are pupae, which is the most difficult life stage to find, greater emphasis is placed on mapping the distributions both of properties with gardens and of those with *P. brassicae* host plants. This information is used to target searching during subsequent periods when *P. brassicae* eggs, larvae and adults are prevalent, thus enabling host-plant-only-general-surveillance and garden-only-general-surveillance.

The frequency with which areas are repeatedly searched for *P. brassicae* is designed to optimise efficiency while minimising butterfly reproduction. The rationale is that *P. brassicae* may lay eggs in an area soon after it has been searched, thus that area should be searched again before those eggs can develop to the pupal stage and become difficult to find. Suitable search frequencies for each month of the year in Nelson were calculated by Kean & Phillips (2014).

Figure 3 shows a comparison between results from general surveillance in autumn 2013 and 2014 that includes data from 21 blocks where ≥100 searches were conducted in the same month in both years. The data were fitted to a generalised linear model with a binomial error distribution and showed a significant decline in detection rates from 2013 to 2014 ($p < 0.001$). The same data are shown in Appendix 4 for each of the 21 management blocks.

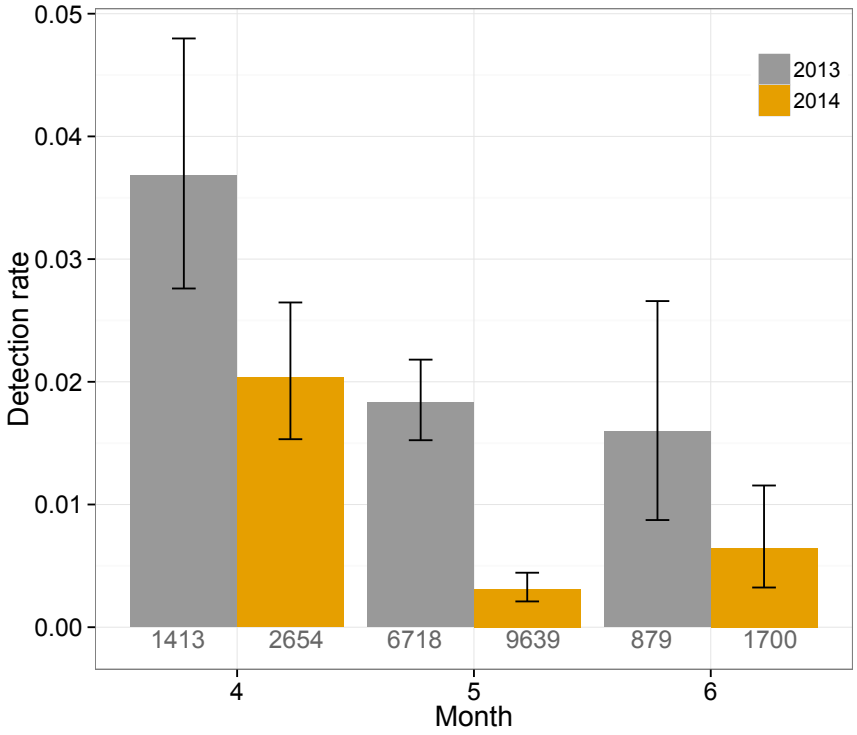

Figure 3. *Pieris brassicae* detection rates from general surveillance conducted April–June in 2013 and 2014, where ≥100 properties per block were searched in the same blocks in the same month in both years. The number of inspections is shown beneath each bar, and error bars show 95% confidence intervals.

6.2 Follow-up surveillance

Follow-up surveillance involves scheduled re-visits to previously infested properties to verify treatment was effective. It is conducted before sufficient time has elapsed for any *P. brassicae* eggs or larvae that survived the first treatment to reach the pupal stage, thus becoming difficult to find. Suitable re-inspection intervals for each month of the year in Nelson were calculated by Kean & Phillips (2014); these are shorter than those defined for general surveillance frequency, previously described, because they assume *P. brassicae* was present and survived treatment, rather than that *P. brassicae* colonised the property after treatment.

Data from follow-up surveillance were used to estimate how many *P. brassicae* survived each successive inspection, and to calculate the number of follow-up inspections required to obtain effective control (Phillips et al. 2014). The results indicated that treatment efficacy has improved through the course of the eradication programme, and that one re-inspection is now sufficient to provide ≥99% confidence that all *P. brassicae* have been eliminated. Further details are given below in the 'Insecticide use' section.

6.3 Passive surveillance

Passive surveillance involves reporting of *P. brassicae* by the public, and is supported by a public awareness campaign. The public are asked to report *P. brassicae* via an 0800 number that is monitored 24/ 7. Staff respond to a passive surveillance report within 48 hours and usually also visit the property to verify it.

Figure 4 shows a comparison of results from passive surveillance between autumn 2013 and 2014. Compared with other surveillance types, detection rates from passive surveillance are high because, after being checked by DOC, most public reports are confirmed to be *P. brassicae* rather

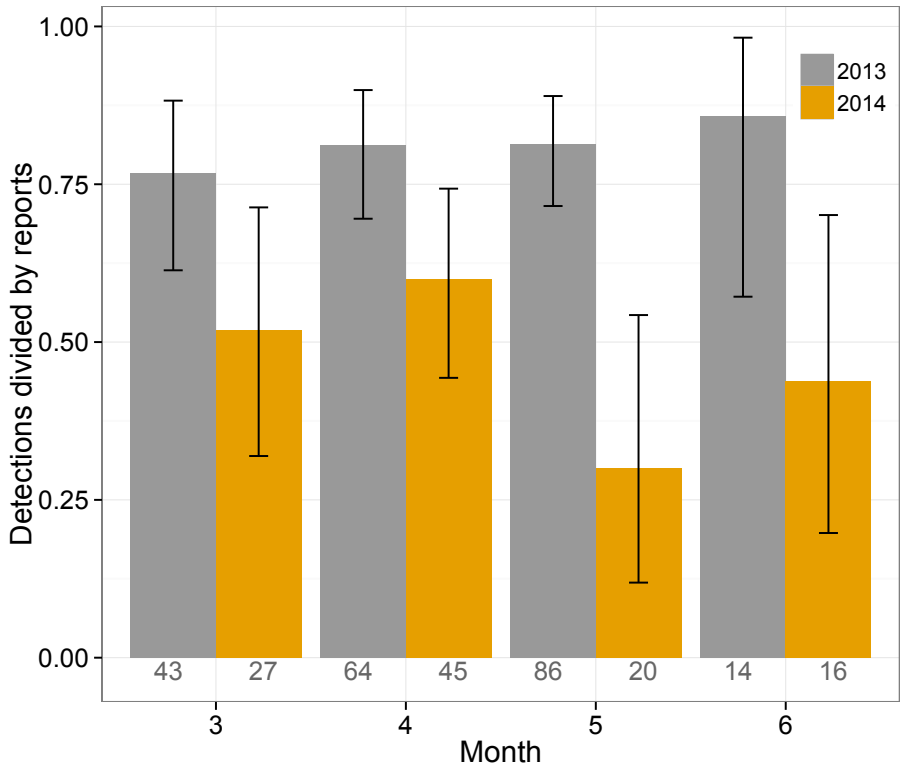

Figure 4. Detections of *Pieris brassicae* divided by passive reports in autumn 2013 and 2014. Number of reports per month is shown beneath each bar, and error bars show 95% confidence intervals.

than some other organism. However, when 2013 and 2014 results in Figure 4 are compared, two things are notable. First, for every month except June, the total number of passive reports was lower in 2014 than in 2013. This was despite considerable publicity in 2014 to stimulate passive reports (see 'Public Awareness' section and Appendix 5). Second, for every month, the proportion of passive reports that was confirmed as *P. brassicae* was lower in 2014 than in 2013. When fitted to a generalised linear model with binomial errors, there were significantly fewer detections per passive surveillance report in 2014 than in 2013 ($p < 0.001$). In each month of 2014, detections per report were significantly lower than in the same month in 2013: March $p = 0.034$, April $p = 0.016$, May $p < 0.001$, June $p = 0.026$. These observations are consistent with a declining abundance of *P. brassicae* in Nelson.

6.4 Active surveillance

Active surveillance involves searching areas that surround properties where passive surveillance reports have been verified, typically within a radius of 50–200 m. This approach was developed early in the eradication programme when staff numbers were low, relatively few properties could be searched, and there was an urgent need to optimise search efficacy. At the time, there was a perception that *P. brassicae* females tended to lay eggs in a spatially aggregated pattern within the scale of a management block, thus the probability of detecting *P. brassicae* should be higher when searching properties nearer to an infested property than those further away. Phillips & van Koten (in prep.) analysed the spatial distribution of properties infested by *P. brassicae* using inspections data from 100 bouts of general surveillance in 26 different blocks, and found that infested properties were aggregated only infrequently. On average, searching all properties within a 300 m radius of a detection would reveal less than half of all the infested properties in the same block (Fig. 5). This relative absence of aggregation, combined with increased staff numbers and advances in general surveillance methods—described below—means active surveillance has been phased out in favour of general surveillance. In autumn 2013, there were 177 detections from 8511 active surveillance inspections (2%), and in autumn 2014 there were 2 detections from 2399 active surveillance inspections (0.08%).

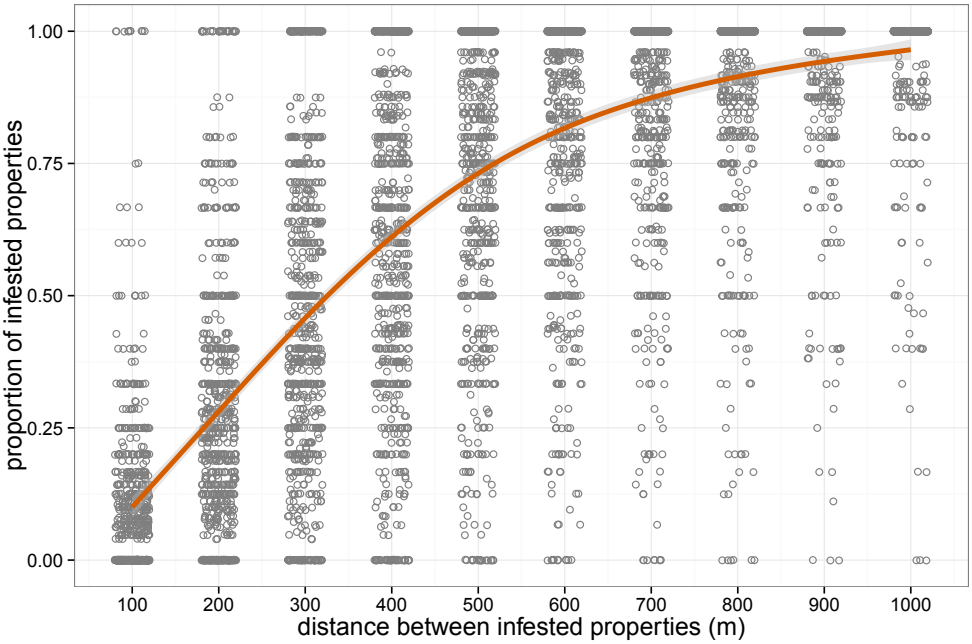

Figure 5. Proportion of properties infested by *Pieris brassicae* by distance between infested properties. Grey ribbon around line shows 95% confidence interval.

6.5 Captures of adults

The eradication programme endeavours to minimise *P. brassicae* reproduction, partly by capturing adults with nets. This is generally difficult and time consuming, but recently became easier when a DOC staff member, William Wragg, developed model butterflies that are attractive to adults of *P. brassicae* and *P. rapae*, particularly males. He initially used *P. brassicae* models made of laminated photocopy paper fixed to commercial toy butterflies that move by solar power. Models made of white satin fabric subsequently appeared more effective than those made from paper. Previous research on *P. rapae* and *P. brassicae* indicates it is ultraviolet reflectance that males are attracted to, and that the underside of the female's hind wing is mostly responsible (Obara 1970). *Pieris* spp. males interact with the models, sometimes even landing on them, as has also been observed by researchers overseas (Obara et al. 2008). While the butterflies are approaching or interacting with the models, they are relatively easy to capture. From 10 October 2014 to 3 November 2014, 180 hours of effort to capture *P. brassicae* adults without a lure yielded one female and two male butterflies. In contrast, 44 hours of effort with a lure yielded six males and one female.

6.6 Searches for pupae

Pupae comprise a large proportion of the *P. brassicae* population during winter and, to a lesser extent, during summer. Pupae are looked for during all general surveillance inspections, but are explicitly targeted on high-risk properties during winter using staff who have previously shown an aptitude for finding them. Properties are selected for pupal searches if mid- to late-stage larvae or pupae are detected on the property after 1 April. Where possible, searchers locate the site of the original detection, then move outwards checking all inanimate objects such as fences, garden sheds and house exteriors. Torches are used to inspect cracks and crevices that could contain pupae. Adjacent properties are searched if larvae are suspected to have crawled off the property to pupate. Data is being collected on the location and state of any pupae found because different generations of *P. brassicae* may show a preference for the same pupation site. Thus, the information is potentially useful for future searches, although no patterns have been noted to date.

6.7 Public awareness

A variety of methods was used during 2013/14 to communicate with the public about the eradication programme, particularly at crucial stages of the *P. brassicae* life cycle (Appendix 5). Two large campaigns, one in spring 2013—the bounty hunt—and another in autumn 2014 asked for the public's help to search for and report *P. brassicae*. The bounty hunt was particularly successful in raising awareness about *P. brassicae* and the eradication programme, and it also provided valuable independent information about the distribution of *P. brassicae* (described in Phillips et al. 2013b).

Other key messages communicated were risks associated with: Accidentally moving *P. brassicae* pupae out of Nelson on vehicles such as campers and caravans, which are often stored near gardens; accidentally moving *P. brassicae* larvae out of Nelson on home-grown brassica seedlings, vegetables and vegetable scraps; and planting winter cover crops such as mustard.

New leaflets and magnets with information about *P. brassicae* were distributed to all households in the Nelson–Tasman area and appeared to raise public awareness, because the number of calls to the MPI hotline increased soon afterwards.

Nelson's refugee community was targeted for engagement with a display at the Nelson Race Unity Day and presentations were given at three English language programmes in Nelson. Advice was sought from local interpreters on building effective relationship with different refugee communities, and several interpreters were contracted to help staff communicate with non-English speakers in the field.

6.8 Blocked access

Sometimes properties cannot be accessed to conduct surveillance, usually due to locked gates, aggressive dogs, or occupants being away, although occupants will occasionally refuse to give permission for their property to be searched. When access is blocked, occupants are left a letter informing them of the situation and reminding them of their obligations under the Biosecurity Act 1993. They are also requested to provide their contact details within a specified time; received details are stored to assist future visits. Occupants who do not respond are visited again, often during a weekend when they are more likely to be home. When repeated attempts to gain access fail, the occupier is warned in writing of the potential for prosecution under the Biosecurity Act, which normally results in access being provided. Currently, 13 properties out of 26 000 inspected (0.05%) have problematic access.

6.9 Management blocks

To assist management and optimise use of staff time, the eradication zone was divided into management blocks. There were 41 blocks in early 2014, then in mid 2014 some blocks were subdivided to create a total of 45 (Fig. 6). Eradication staff are allocated to teams and teams are assigned to blocks with schedules for completing their searches, as defined both by previous experience of the time required to search each block, and by the phenology of *P. brassicae*. The time required to search an entire block varies with the number and types of properties per block, the amount and nature of vegetation present, and ranges from 1 to approximately 58 person-days. Usually, different teams will work in separate blocks concurrently, which simplifies management and provides flexibility for dealing with unpredictable challenges. For example, teams that are ahead of schedule can be used to respond quickly to new detections arising from passive surveillance outside of the blocks being searched, or to support teams that are falling behind with their general surveillance. This enables efficient use of staff time and helps to ensure that the overall search system stays on schedule.

The order and frequency of block searches are defined by carefully evaluating their relative importance to eradication success. This ensures that those blocks where inspections are most vital receive particular attention, especially during the critical autumn and spring periods when nearly all *P. brassicae* individuals are exposed to control. Priorities are re-evaluated at least seasonally, and more often if required. Phillips (2014) discussed some factors that either are, or could be, considered when prioritising blocks. The main ones currently considered are:

- Maximising *P. brassicae* mortality in spring and autumn by targeting blocks where its abundance is expected to be high.
- Minimising spread of *P. brassicae* beyond the eradication zone by targeting blocks that are on the zone's periphery.
- Minimising dispersal of *P. brassicae* into green areas that are difficult to manage by targeting any *P. brassicae* that are nearby.

6.10 Prioritising individual properties

To enable explicit targeting of high-risk locations, individual properties are allocated to one of three categories: Tier one properties are those where *P. brassicae* or nasturtium (a favoured host plant) have previously been detected; Tier two properties include all tier one properties, plus those known to have *P. brassicae* host plants; Tier three properties include all tier one and two properties, plus those that have gardens.

Block ID	Block Name
1	Arapiki
2	Atawhai North
3	Atawhai South
4	Bishopdale
5	Brook North
6	Brook South
7	CBD
8	Centre of NZ
9	Cleveland
10	Colleges
11	Enner Glynn
12	Grampians
13	Hardy
14	Hill Street North
15	Hill Street South

Block ID	Block Name
16	Isel
17	Karaka
18	Konini
19	Lud Valley
20	Maire
21	Moana North
22	Moana South
23	Nayland North
24	Nayland South
25	Ngawhatu
26	Ngawhatu Hills
27	Port Nelson
28	Richmond North
29	Richmond South
30	Saxton

Block ID	Block Name
31	Stepneyville
32	Stoke Industrial
33	Tahuna Flats
34	Tahuna Industrial
35	Tamaki
36	The Wood
37	Tipahi
38	Toi Toi North
39	Toi Toi South
40	Vanguard
41	Wakapuaka
42	Washbourne
43	Washington North
44	Washington South
45	Maitai

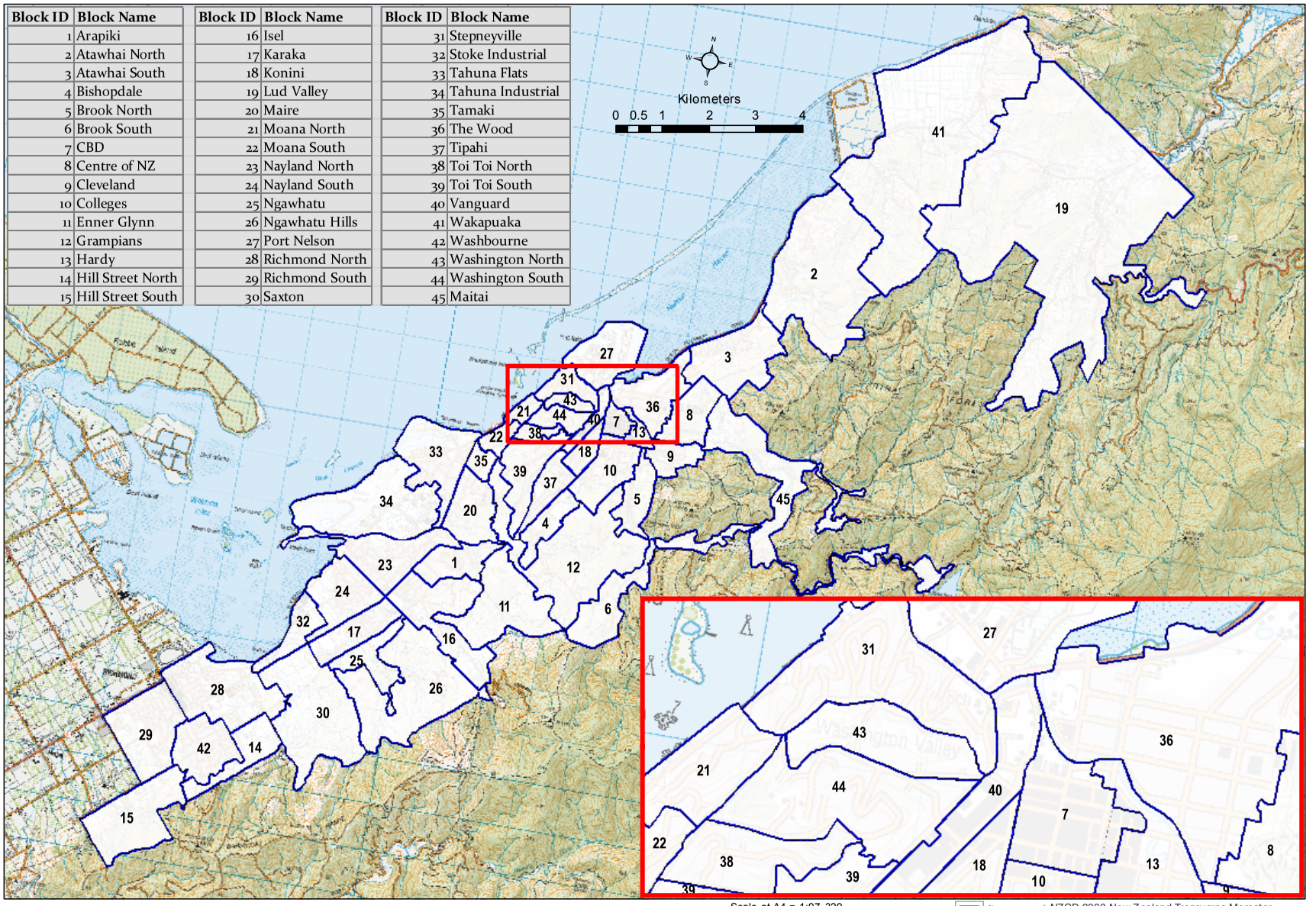

Figure 6. *Pieris brassicae* management blocks in Nelson.

Prioritisation of individual properties supports efficient use of staff time and effective control of *P. brassicae* within the block-ranking framework because general surveillance can be conducted by targeting properties within the risk categories, with the highest priority (tier three) properties searched first.

6.11 Host plant preference

Nelson properties were surveyed from January 2012 to August 2013 to count the *P. brassicae* host plants that were present. The data are not yet ready for proper analysis, and the following text only describes what they seem to suggest at first glance. Some of the host plant survey data are summarised in the left-hand column of Figure 7. Nasturtium appeared dominant in all seasons, though slightly less so in winter when broccoli and Brussels sprout increased in prevalence. The right-hand column of Figure 7 shows the proportions of the same host plants on which detections of *P. brassicae* occurred between May 2010 and July 2014. The proportion of detections that occurred on nasturtium was broadly similar to the proportion of nasturtium found during the property survey; nasturtium appears to be a key host plant for *P. brassicae* in Nelson. However,

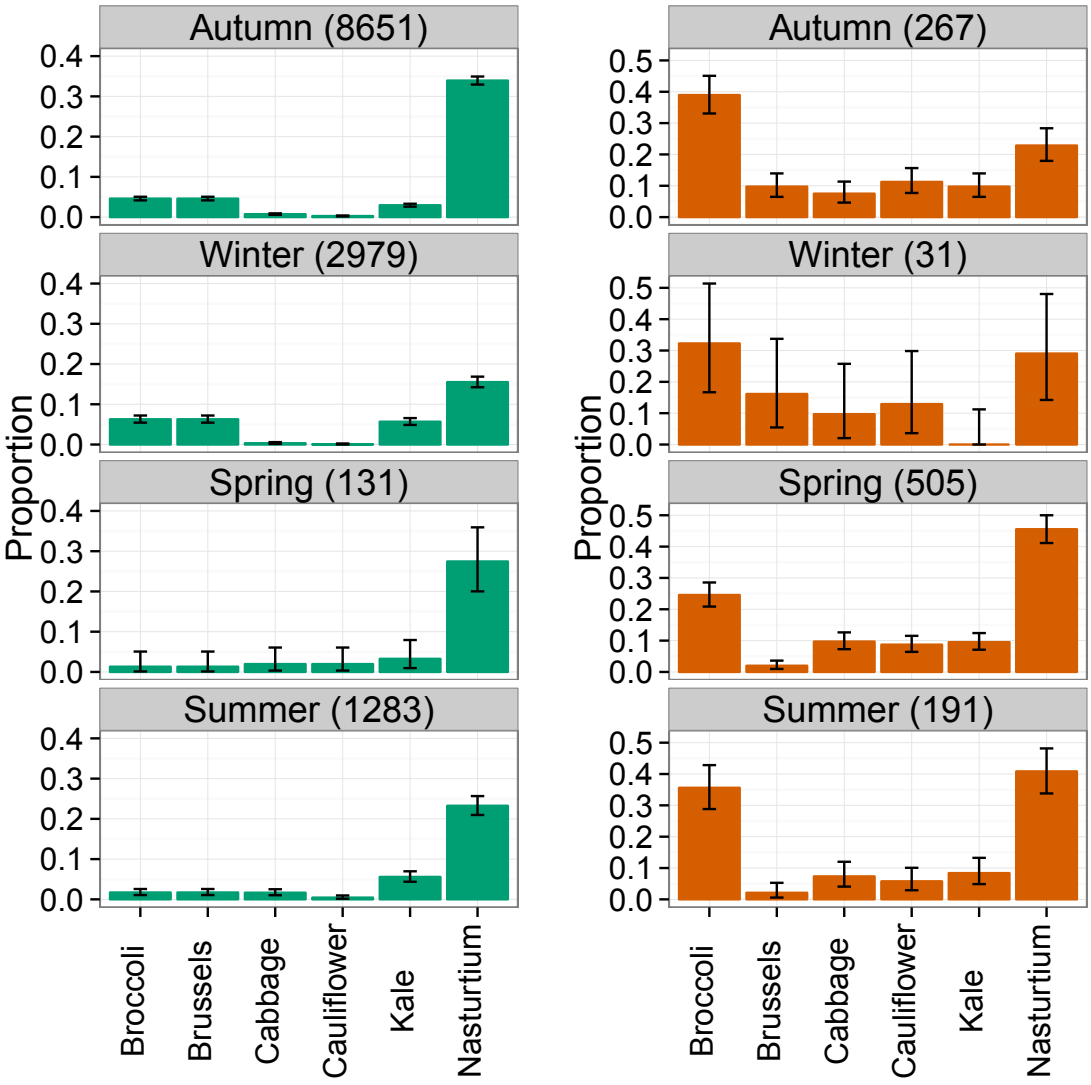

Figure 7. The left-hand column of green histograms shows the proportions of various host plants of *Pieris brassicae* recorded during a survey of Nelson properties conducted from January 2012 to August 2013. The right-hand column of red histograms shows the proportions of various host plants on which *P. brassicae* detections occurred between May 2010 and July 2014. Total properties searched shown in brackets. Error bars indicate 95% confidence intervals.

the proportion of detections that occurred on broccoli appears higher than the proportion of broccoli found during the property survey, which suggests *P. brassicae* might favour broccoli when it is available. Alternatively, *P. brassicae* might be detected more often on broccoli because broccoli is easily searched.

6.12 Host plant control

Sites with host plants that require control are initially identified by surveillance staff. If the vegetation covers a large area (e.g. >5 m^2) or is difficult to access, usually due to steep terrain, then it is reported to the Host Plant Coordinator (see 'Team structure' section). Host plant patches are prioritised for control based on their size and proximity to *P. brassicae*, and after being controlled are re-inspected as required.

In 2013/14, the surveillance teams controlled host plants on approximately 3000 properties. The host plant control team treated an additional 130 properties that had large infestations, primarily of nasturtium, 80 manually and 50 with herbicide. NELMAC was contracted to manage 12 large host plant patches that were difficult to access. The DOC Golden Bay abseiling team conducted three cliff inspections, removed large areas of nasturtium, and further cliff inspections are scheduled.

6.13 Insecticide use

Prior to November 2013, the eradication programme made limited use of insecticide, and properties were disinfested mainly by manually removing all *P. brassicae* individuals found and destroying them. Following a review by Briden & Broome (2013) and on TAG advice, insecticide use increased from November 2013:

- On 8 November 2013, the treatment protocol was changed to insecticide-spray all host plants on which *P. brassicae* larvae were found.
- On 2 December 2013, the protocol was intensified to insecticide-spray all *P. brassicae* host plants present on a property whenever larvae were found.
- On 16 January 2014, the protocol was further intensified to insecticide-spray all *P. brassicae* host plants present on a property whenever eggs or larvae were found. This coincided with the addition of an oil to the insecticide to increase mortality of eggs.

The insecticide used is organic (Bio-Gro certified Entrust Naturalyte) with horticultural oil (D-C-Tron) added to improve spray coverage and increase efficacy against eggs. Spraying is nearly always conducted after gaining consent from property occupants, but occasionally occurs without consent when late-stage larvae are found and occupants do not communicate. A few occupants resist insecticide use, either because they have bee hives or are averse to chemical sprays, and their properties are managed on a case by case basis. Offering an alternative microbial insecticide (*Bacillus thuringiensis*) that is of low risk to bees is being evaluated for use in these situations.

Phillips et al. (2014) used data from follow-up surveillance, previously described, to calculate high and low estimates of the proportions of properties where some *P. brassicae* had been overlooked in the previous inspection. High estimates assumed that all *P. brassicae* found in a follow-up inspection had been missed in the previous inspection. Low estimates used *P. brassicae* development rate data and the time elapsed between successive inspections to evaluate if the *P. brassicae* found could have developed from eggs laid after the previous inspection; if they could have, then they were not classified as overlooked. Figure 8 shows how the proportions overlooked have declined with time. The proportions overlooked were calculated for the periods April–May 2013, September–October 2013 and February–June 2014, and the following figures are the differences between the medians of the high and low estimates for those periods. The

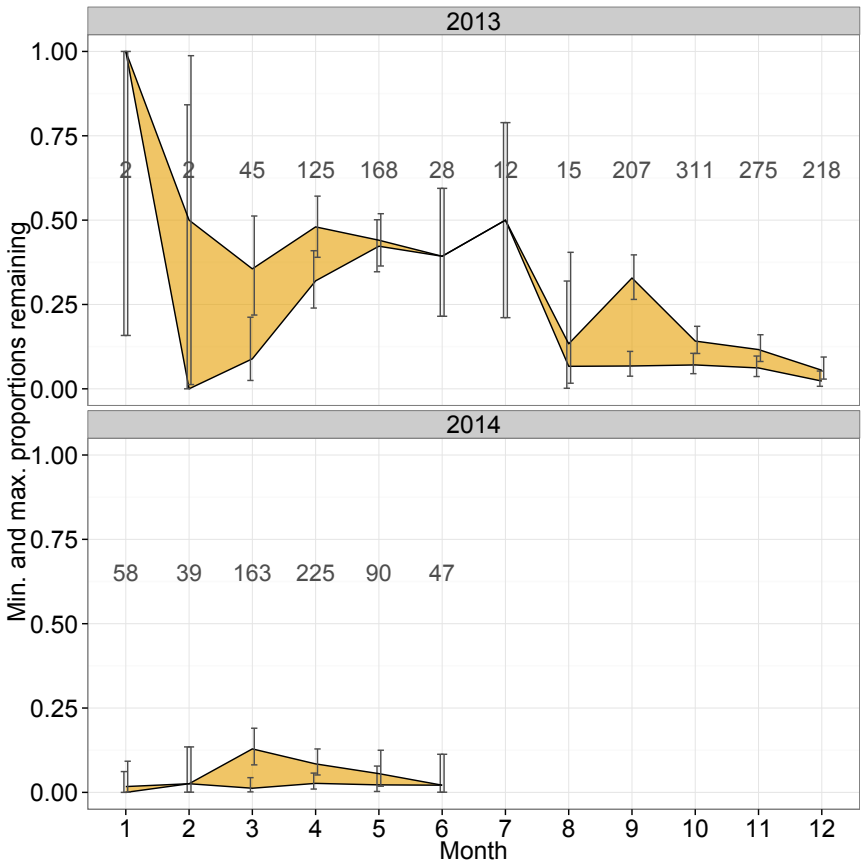

Figure 8. High and low estimates of proportion of properties with some *Pieris brassicae* remaining after previous inspection, by year and month. Digits show number of inspections, error bars show 95% confidence intervals.

proportion declined by 27% between April–May 2013 and September–October 2013, apparently due to improvements in staff expertise and search protocols, then declined by a further 9% in 2014, apparently due to increased insecticide use. Thus, searching combined with host plant treatments now eliminates *P. brassicae* from 89–99% of infested properties. A further follow-up inspection provides ≥99% confidence that properties have been effectively treated.

7. *Pieris brassicae* genetics

A genetic analysis of Nelson's population of *P. brassicae* found three haplotypes (i.e. variants showing small genetic differences) in the 'barcode' region of the mitochondrial cytochrome oxidase I gene (Hiszczynska-Sawicka & Phillips 2014). This variation can assist DOC's attempt to eradicate *P. brassicae* in several ways:

- Identifying whether a re-occurrence of *P. brassicae* in an outlying area is due to control failure or to or reinvasion from central Nelson.
- Identifying whether different batches of eggs and larvae on nearby properties are the progeny of one or several females.
- Providing information about individual females' spatial and temporal patterns of movement and oviposition.
- Providing supporting evidence of declines in *P. brassicae* population size because the haplotypes should progressively disappear from the population as it nears extinction.
- Identifying whether additional *P. brassicae* are arriving in New Zealand from overseas.

A rapid and inexpensive method of identifying each haplotype was developed (Phillips & Sawicka 2014) and is being used to analyse *P. brassicae* specimens sent to AgResearch by DOC. To date, the haplotypes of over 300 specimens have been identified and analysis of the results is pending. Table 2 summarises the *P. brassicae* haplotypes by the season they were detected.

Table 2. Numbers and proportions of each of three *Pieris brassicae* COI haplotypes detected in Nelson, by season.

	NUMBER OF SPECIMENS			PROPORTION OF SPECIMENS		
	A	B	C	A	B	C
Summer 2012/13	1		1	0.50	0.00	0.50
Autumn 2013	1			1.00	0.00	0.00
Winter 2013	6	1	1	0.75	0.13	0.13
Spring 2013	21	9	4	0.62	0.26	0.12
Summer 2013/14	46	5	5	0.82	0.09	0.09
Autumn 2014	135	19	9	0.83	0.12	0.06
Winter 2014	20		1	0.95	0.00	0.05
Spring 2014	20	5	2	0.74	0.19	0.07
Total	250	39	23	0.80	0.13	0.07

7.1 Delimitation

Monitoring for the presence of *P. brassicae* outside the eradication zone depends mainly on passive surveillance and regular monitoring at sites in the Tasman region by Plant and Food Research and DOC.

From July 2013 to June 2014, passive reports that proved not to be *P. brassicae* were received from 48 locations outside the Nelson eradication zone, including places as far afield as Whangarei, Auckland, Wellington and Christchurch. Locations near to Nelson such as Mapua and Motueka were also represented.

Plant and Food Research staff surveyed brassica crops at six locations outside the perimeter of the eradication zone (Fig. 9) 15 times between September 2013 and May 2014 and found no *P. brassicae*.

DOC regularly surveys six native cress populations near Nelson (Fig. 10) and these were checked twice in 2013/14; no *P. brassicae* were found.

8. Natural mortality

In addition to the suppressive effects of the eradication programme on *P. brassicae*, natural mortality will also be having an impact. In Denmark, immature stages of *P. brassicae* suffered 97% mortality from natural causes, mostly parasitism and predation (Kristensen 1994). In England, natural mortality of immature stages of *P. rapae* was estimated at 90% (Dempster 1967). In Nelson, several parasites and predators are helping to suppress *P. brassicae*.

8.1 Parasitism

Pieris brassicae larvae collected in Nelson are frequently parasitised by *C. glomerata*, a small parasitic wasp that was originally released in the early 1930s as a biological control agent for *P. rapae* (Cameron *et al.* 1989). It was later found that *C. glomerata* prefers *P. brassicae* to *P. rapae*, which is fortuitous, because *P. brassicae* must now contend with a natural enemy that is already abundant throughout New Zealand.

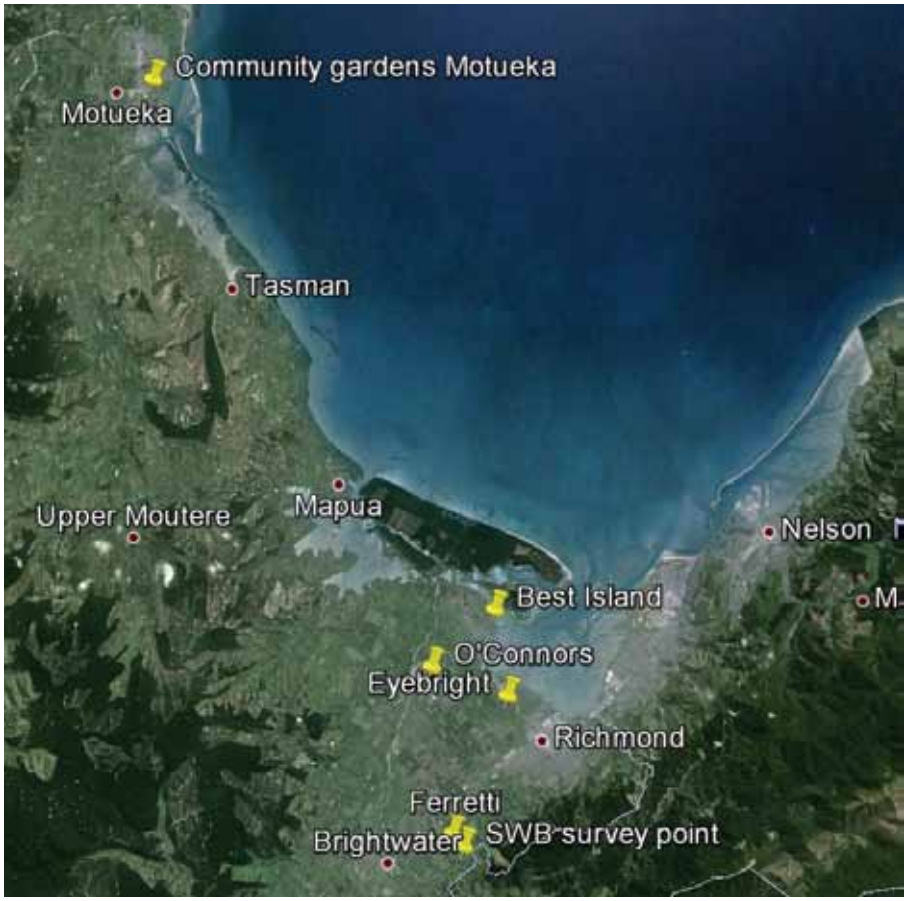

Figure 9. Brassica crops near the eradication zone where Plant and Food Research regularly monitors for *P. brassicae*.

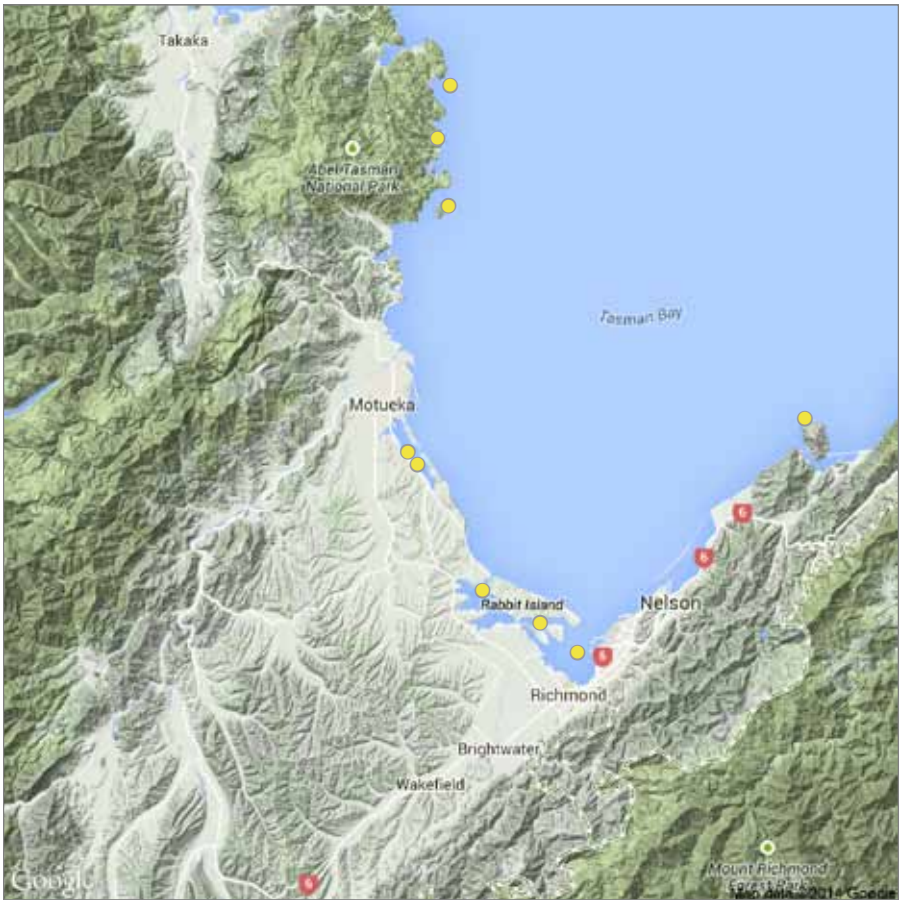

Figure 10. Native cress populations near Nelson where DOC regularly monitors for *Pieris brassicae*.

Cotesia glomerata females lay dozens of eggs at a time in young *P. brassicae* larvae, which hatch into grubs that consume the host larva from the inside. The host larva continues feeding on brassicas until it is nearing pupation, whereupon the *C. glomerata* grubs chew their way out of the larva, killing it in the process, then form bundles of yellow cocoons in which to pupate. Adult parasitic wasps emerge from the cocoons to begin the cycle again.

In Nelson in 2013/14, an average of at least 35% of *P. brassicae* larvae were parasitised by *C. glomerata*, with the proportion exceeding 72% in May and June. These proportions are probably underestimates due to details of the method used to measure parasitism. Parasitism rates of *P. brassicae* by *C. glomerata* exceeding 80% have been reported in Denmark (Kristensen 1994) and India (Kumar 2012). There is evidence overseas that parasitism rates of *P. brassicae* by *C. glomerata* varies with host plant, and could be lower in nasturtium (cited in Feltwell 1982, p. 410). It is probable that *C. glomerata* is playing a significant role in suppressing the growth and spread of the *P. brassicae* population in Nelson.

Pieris brassicae larvae that pupate become vulnerable to a second parasitic wasp, *Pteromalus puparum* L. (Hymenoptera: Pteromalidae), which was also introduced to New Zealand in the 1930s as a biological control agent for *P. rapae* (Cameron et al. 1989). Although *P. puparum* is parasitising *P. brassicae* in Nelson, the proportion parasitised is unknown because *P. brassicae* pupae are difficult to find and are seldom detected. Muggeridge (1943) reported up to 89% of *P. rapae* pupae collected in Hawke's Bay, New Zealand, were parasitised. The female *P. puparum* can parasitise up to 18 *P. rapae* pupae and produce up to c. 700 offspring (Muggeridge 1943). She injects eggs into a young *P. brassicae* pupa, which hatch into grubs that consume the *P. brassicae* pupa from the inside and kill it. Once the grubs finish growing, they pupate inside the dead *P. brassicae* pupa, and 194–697 wasp adults emerge (Muggeridge 1943) to begin the cycle again.

8.2 Enhancing natural parasitism to assist eradication

As the eradication programme progresses, *P. brassicae* will become increasingly difficult for staff to find, and eliminating the last remaining individuals could become a significant challenge. Parasitic wasps are well known for their remarkable ability to find their host insects, even when hosts are scarce. Therefore, supplementing parasite populations by releasing laboratory-cultured populations in locations where *P. brassicae* occurs in low densities could assist suppression, and work is underway to enhance populations of *C. glomerata* and *P. puparum* in Nelson.

Plant & Food Research staff collect *C. glomerata* cocoons from *P. rapae* in several New Zealand locations, and DOC and Entecol collect them from *P. brassicae* in Nelson. DOC staff in Nelson maintain the cocoons until the adult wasps emerge, which mate soon afterwards. The wasps are provided with sugar water, then released. In autumn 2014, c. 20 000 *C. glomerata* cocoons were collected, about 17 000 of them by Plant & Food Research, of which >50% reached the adult stage and were released in locations where there had either been repeated recent *P. brassicae* detections, recent detections in areas that are difficult to search, or few recent detections in a peripheral block.

A method for mass rearing the parasite of *P. brassicae* pupae, *P. puparum*, has been developed by AgResearch at Lincoln. This involves collecting *P. rapae* adults, having them lay eggs on host plants and rearing their larvae to the pupal stage, whereupon they can be used as hosts for *P. puparum*. The intention was to start releasing *P. puparum* in Nelson in late autumn 2014, but the *P. rapae* culture at AgResearch became infected with a disease, which prevented production of sufficient parasitic wasps. The *P. rapae* colony has since been re-established, and the first *P. puparum* should be available for release in summer 2014/15.

In Nelson, eradication staff collect any *P. brassicae* pupae they find during property inspections and maintain them to measure parasitism rates. Any *P. puparum* that emerge can then be released. Few pupae were found this autumn, only one of which produced *P. puparum* adults, and these were released in an area where late instar *P. brassicae* larvae had recently been found.

8.3 Predation

When disturbed, *P. brassicae* larvae often vomit a dark green fluid containing chemicals that deter some predators. This behaviour has a fitness cost, and fewer caterpillars vomit when they are in large groups (Daly et al. 2012). The bright colouration of late instar *P. brassicae* larvae is also thought to deter some predators. Despite these defences, predation plays an important role in regulating *P. brassicae* populations (Baker 1970). *Pieris brassicae* larvae feed in clusters, which means entire broods can be efficiently predated.

8.3.1 Wasps

Three species of introduced social wasps (Hymenoptera: Vespidae) occur in Nelson: *Vespula vulgaris* (L.) (common wasp), *V. germanica* (F.) (German wasp), and *Polistes chinenis antennalis* Pérez (Asian paper wasp). In Europe, both *V. vulgaris* and *V. germanica* predate larvae of *P. brassicae* (Brodmann et al. 2008). In Nelson, *Vespula* spp. adults usually reach high numbers in late January, peak in February and March, and continue to forage during April and May, which coincides well with the autumn flush of *P. brassicae* larvae.

Polistes chinenis antennalis is a predator that prefers lepidopterous larvae and can occur in very high densities in New Zealand (Ward & Ramon-Laca 2013); it can be an effective control agent of *P. rapae* in cabbages (Gould & Jeanne 1984) and its most common prey in Northland, New Zealand, was *P. rapae* (Clapperton 1999). In Nelson, *P. chinenis antennalis* has been observed taking *P. brassicae* larvae from nasturtium (W. Wragg, pers. comm.). As with the *Vespula* spp., densities of *P. chinenis antennalis* adults peak in March.

Together, the three wasp species will have their greatest impacts on *P. brassicae* larvae during mid-summer to autumn. Wasps will often return to plants where they previously found prey (Toft 2001), so are likely to remove entire broods of larvae .

8.3.2 Ants

Ants (Hymenoptera: Formicidae) prey on *Pieris* spp. larvae (Jones 1987) and *Linepithema humile* (Mayr) (Argentine ant) has been observed preying on early instar *P. brassicae* larvae feeding on nasturtium in Nelson (J. Rees, pers. comm., 28 February 2013). The main *L. humile* populations in Nelson occur in areas where *P. brassicae* is less abundant, such as The Wood, Brougham St and Stoke. They forage from September to May (Toft, pers. obs.), so coincide with the periods when most *P. brassicae* larvae are present, though they disappear during extended periods of drought (Toft 2011). Other common ant species in Nelson that are likely to feed on *P. brassicae* eggs and larvae include the New Zealand native *Monomorium antipodum* Forel (southern ant) and introduced species such as *Pheidole rugosula* Forel (big-headed ants), *Tetramorium grassi* Emery (pennant ants) and *Ochetellus glaber* (Mayr) (black house ants).

8.3.3 South African praying mantis

Over the last decade, *Miomantis caffra* Saussure (Mantodae: Mantidae), South African praying mantis, has become one of the most commonly seen insects in residential gardens in Nelson. It is a voracious predator of other insects and has been observed taking 4th instar *P. brassicae* larvae on broccoli (W. Wragg, pers. comm., June 2013) and *P. rapae* adults (A. McMahon, pers. comm.). They are active throughout the year, but adults are most abundant in Nelson in autumn and early winter, which coincides with a peak period of *P. brassicae* activity.

8.3.4 Other invertebrates

Many other invertebrates known to attack *P. rapae*, including spiders, harvestmen and predatory beetles (Dempster 1967), are likely to also prey on *P. brassicae*. *Phalangium opilio* (European harvestman) was amongst the most important predators of young *P. rapae* larvae (Dempster 1967) and is very common in Nelson gardens. Other probable predators include *Cermatulus nasalis* (a predatory shield bug), *Micromus tasmaniae* (Tasmanian lacewings), and various spiders including large orbwebs, which should even be capable of capturing *P. brassicae* adults.

8.3.5 Birds

Northern hemisphere research has shown that birds are important predators of *P. brassicae* (Baker 1970, Kristensen 1994). Eleven times as many *P. brassicae* larvae survived to the pre-pupal stage if host plants were protected from birds (Kristensen 1994). In England, *P. brassicae* was predated by a succession of bird species as it developed through its immature stages. Garden warblers and house sparrows fed on eggs, tits preferred early instar larvae, and later-stage larvae were more often taken by larger ground-feeding birds such a blackbirds and song thrushes (Baker 1970). One thrush destroyed a brood of 40 early instar *P. brassicae* larvae (Baker 1970). Bird predation of *P. brassicae* will certainly be occurring in Nelson although, to date, it has only been reported by one resident.

8.4 Disease

Pieris brassicae is susceptible to a range of microsporidian, fungal, viral and bacterial infections. While there can be outbreaks of disease, particularly of granulosis virus, death rates are probably only in the order of about 5% (Dempster 1967; Kristensen 1994). Disease incidence in the Nelson population of *P. brassicae* is unknown.

8.5 Weather

During rain, LI-III *P. brassicae* larvae can drown in small pools of water on leaves (Harcourt 1966, Le Masurier 1994), and higher humidity can increase disease incidence (Dempster 1967). Hail is deadly to caterpillars and eggs on exposed surfaces (Baker 1970). Violent weather can dislodge eggs, larvae and adults from plants, which may injure them, expose them to new predators, and interrupt larval feeding. Cool, dull weather can reduce *P. brassicae* reproduction by inhibiting flying, mating, nectar-feeding and egg laying by adults (Dempster 1967). A preliminary assessment found no obvious evidence that rainfall in Nelson reduced *P. brassicae* detection rates or numbers found per search.

9. Management activities

9.1 DOC and MPI roles and responsibilities

MPI is New Zealand's lead biosecurity agency with responsibilities to protect environmental, economic and health values under the Biosecurity Act 1993, while DOC has a responsibility to protect native biodiversity under the Conservation Act 1987. MPI handed over the *P. brassicae* incursion response to DOC on 19 November 2012. DOC immediately initiated the eradication attempt and remains the lead agency. MPI supports DOC by providing research funding of $72,000 per year until 30 June 2015 and by maintaining the New Zealand biosecurity hotline (0800 80 99 66).

9.2 Team structure and communications

Figure 11 shows the *P. brassicae* eradication programme management structure and roles. The team is led by a Project Manager who reports to a senior manager within DOC. The *P. brassicae* TAG and technical advisor provide advice and support to the whole team via the Project Manager. The Operations Manager directs staff as part of day-to-day operations that include *P. brassicae* surveillance and control, host plant control and information management.

Each surveillance team consists of a Team Leader and, typically, four Rangers, one of whom is assigned to be 2IC to cover any Team Leader absences. Each team is assigned to a management block. Team size is sometimes increased to eight to make faster progress through larger blocks. Teams are issued with VHF and UHF radios to facilitate field communications within teams, between teams, and with base. Team Leaders also carry mobile phones. Five field teams operated in spring 2013 (September–November) and seven teams in autumn 2014 (March–May). By spring 2014, eight teams were in the field. Six focused on general or active surveillance, one on host plants and another on responding to passive reports and carrying out follow-up visits to positive finds. During this period, c. 35 staff worked in the field each week day.

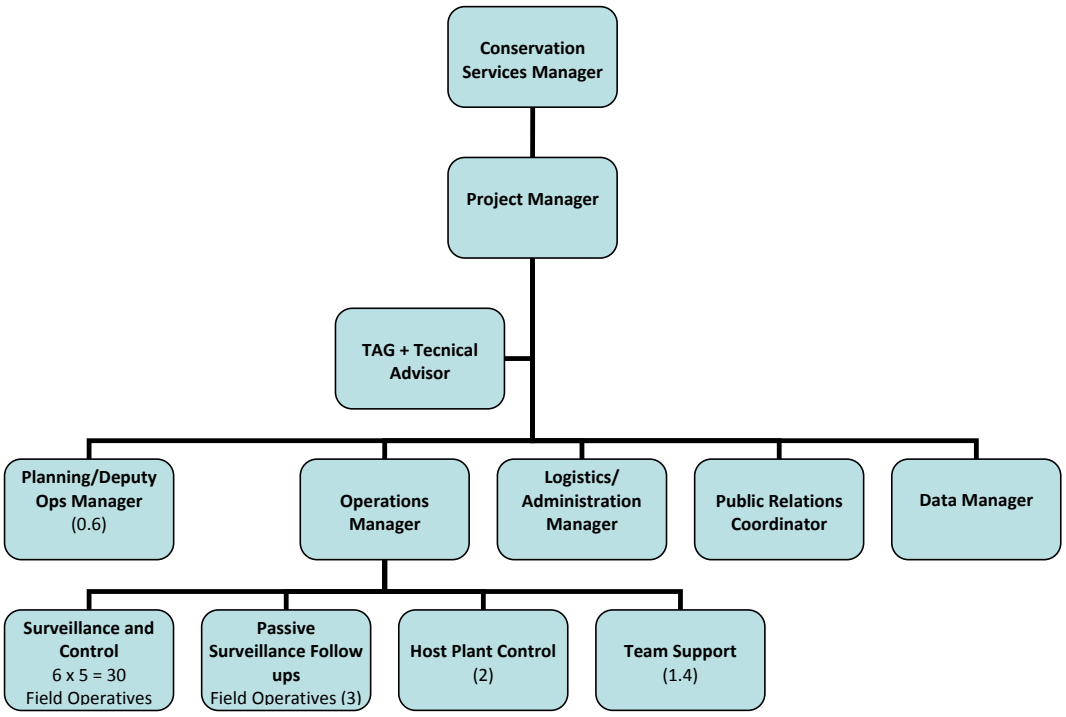

Figure 11: *Pieris brassicae* eradication programme management structure

Operations meetings are held weekly to discuss progress and issues. Topics discussed include host plant control, advocacy, training, health and safety, and administration. Team Leaders inform Rangers in their team of any relevant developments or operational changes as they arise, and meeting minutes are circulated to Team Leaders and Rangers. Meetings involving all team members are also held to discuss progress, programme refinements and future directions.

9.3 Data management

Pieris brassicae eradication data is managed in DOC's enterprise Geospatial Information System (GIS). This is built on ESRI's ArcGIS Server, which publishes data held within the Spatial Database. Presentation and data management occurs through two main user interfaces, which offer different capabilities:

- ArcGIS Desktop software is used for detailed spatial analysis and for interactive map production. Dynamic queries highlight addresses with the highest priority for follow-up. Desktop is also used to update the underlying Nelson cadastre map, which ensures teams revisit the correct addresses.
- Web GIS (Geocortex Essentials) is used to enter inspection data and performance actions relating to detections.

Field work is prioritised by discrete geographical blocks which are also managed within the system. Field teams take an inspection sheet and map into the specified area and record the presence or absence of *P. brassicae*. When it is found, the life stages involved are recorded, as are details about host plants and information useful for future visits to the property. Upon returning to the office, information recorded on the field sheets is transferred to the data entry forms in the web application. Field information is entered in the electronic system as soon as practicable, typically within 48 hours. The data is made available to stakeholders and partners via exports from the central database on DOC's network.

Mobile technology could potentially reduce the field team's time in the office, but would bring an additional layer of complexity, which last season (2012/13) was considered too risky. A hardware and software upgrade (ArcGIS 10.2) is currently underway.

9.4 Health and safety

A comprehensive health and safety plan (DOCDM-1395913) was developed to manage risks associated with surveillance and eradication tasks. A health and safety representative, Derek Walker, was appointed and staff are encouraged to provide feedback, building a positive health and safety culture and an effective incident reporting system. All near misses and incidents are logged, investigated and captured in RiskManager/DOCLearn.

9.5 Training

Authorised Persons training is provided to give staff statutory appointment under the Biosecurity Act (1993) for conducting *P. brassicae* control and compliance roles, which includes police-vetting and employment checks prior to appointment. All staff are issued with identification and an Instrument of Appointment as an Authorised Person to present to members of the public when requested. The induction process includes field training, provision of uniform/PPE. Training is also provided to manage staff competency and risks associated with:

- Dog behaviour
- First aid
- Chemical use and spray application
- Anaphylaxis

Accumulative stress from over-exposure to aggressive dogs and confrontational situations are managed through Toolbox Talks carried out by Team Leaders and weekly discussions at operations meetings. Hazards are managed by the Operations Manager, Simon Bayly.

9.6 Technical Advisory Group

The *P. brassicae* Technical Advisory Group (TAG) is led by Kerry Brown, a Threats Technical Advisor with DOC in Nelson with wide experience in animal and plant pest eradication and management. He is supported by Dr Chris Green, a Threats Technical Advisor with DOC in Auckland who is an entomologist with extensive insect pest management experience. Keith Broome is a Senior Threats Technical Advisor with DOC in Hamilton who leads DOC's Island Eradication Advisory Group that provides pest eradication advice nationally and internationally. Graham Walker is a research entomologist with Plant & Food Research in Auckland and has extensive experience in insect pest management focussed on biological control in vegetable and forage crops in New Zealand. Dr Craig Phillips is a senior scientist with AgResearch in Lincoln with extensive research experience in biosecurity and insect pest management. Richard Toft provides additional technical advice. Richard is an experienced invertebrate ecologist focussed on ecology and management of invasive invertebrates and is managing director of Entecol Ltd. in Nelson.

The *P. brassicae* TAG meets twice yearly (May and November) to provide strategic advice and assess progress using the most recent autumn or spring results. The TAG also provides advice in response to specific operational questions and data analysis, critical peer review and strategic planning support.

9.7 Research

Research projects funded by MPI in 2012/13 were:

- Plant and Food Research (M. Suckling et al.) to develop *P. brassicae* attractants.
- Plant and Food Research (G. Walker et al.) to develop *P. brassicae* traps.
- AgResearch (C. Phillips and J. Kean) to develop a phenology model for *P. brassicae*.

Research projects funded by MPI in 2013/14 were:

- Plant and Food Research (M. Suckling et al.) to develop *P. brassicae* attractants.
- David Rees to train a *P. brassicae* detection dog.
- AgResearch (C. Phillips and J. Kean) to analyse surveillance records to support robust decision making.
- AgResearch (C. Phillips and E. Sawicka) to develop *P. brassicae* genetic methods to assist eradication.

Proposed research projects in 2013/14 that were not funded were:

- Entecol (R. Toft) to develop a *P. brassicae* trap
- AgResearch (S. Hardwick and C. Phillips) to breed parasitic wasps for release in the eradication zone to help control *P. brassicae*.

9.8 Reviews

Keith Briden and Keith Broome, both senior technical threats advisors with DOC, reviewed the *P. brassicae* programme in August 2013 (Briden & Broome 2013). Their main recommendations were:

- Increase public awareness and community involvement.
- Use insecticide more often.

- Develop a communications plan.
- Forge commitment to eradication at all levels of the project.

All recommendations were implemented.

MPI convened an External Technical Advisory Group (ETAG) to meet on 12 December 2013. The group included: Dr Mandy Barron (Scientist, Landcare Research), Dr Jacqueline Beggs (Associate Professor Biodiversity, Biodiversity and Conservation, University of Auckland), Dr Ecki Brockerhoff (Principle Scientist, Forest Entomology, Scion), Dr Stephen Goldson (Principle Scientist, AgResearch), Dr Mark Hoddle (Director, Center for Invasive Species Research, UC-Riverside, USA), Dr Margaret Stanley (Senior Lecturer, Biodiversity, Biodiversity and Conservation, University of Auckland) and Dr Patrick Tobin (Research Ecologist, USDA Forest Service, USA).

The ETAG were provided with an interim report (Phillips et al. 2013b) and an updated feasibility assessment (Phillips et al. 2013a), plus other information prior to the meeting on the 12 December. Kerry Brown, Dr Chris Green and Dr Craig Phillips were present at the meeting and answered questions from the ETAG. The purpose of the meeting was for the ETAG to provide advice on operational efficiency, tools and techniques, the likelihood of success and recommendations for improvement. MPI, who led the process, concluded from the meeting that there was insufficient data for the ETAG to review the programme.

9.9 Reporting and presentations

The *P. brassicae* eradication plan (Toft et al. 2013) presented initial plans for the eradication attempt, and a summary of the programme for 2012/13 was produced in August 2013 (Toft 2013). A report was prepared for the MPI ETAG, which described methods and results to December 2013 (Phillips et al. 2013b). Eradication feasibility was assessed three times by the *P. brassicae* TAG: September 2013 (Green et al. 2013), November 2013 (Phillips et al. 2013a) and November 2014 (summarised in this document).

DOC contracted an economist with the Institute for Rural Futures, University of New England, Armidale, NSW, Australia to prepare a benefit cost analysis for eradicating *P. brassicae* (East 2013a). It concluded that the *P. brassicae* eradication programme was warranted based on high net present values and benefit cost ratios. The impact of *P. brassicae* on New Zealand native cresses was also evaluated (East 2013b).

Chris Green (DOC) gave presentations about the *P. brassicae* eradication programme to various stakeholders during the year including: The New Zealand Biosecurity Institute at its NETS conferences in July 2013 (Greymouth) and August 2014 (New Plymouth); DOC Transformation and Threats Workshop in May 2014 (Wellington); Better Border Biosecurity Conference in May 2014 (Wellington); Vegetables New Zealand AGM in June 2014 (Auckland); Entomological Society, Auckland Branch, in September 2014 (Auckland); and B3 Science Partnership Forum Meeting in October 2014 (Auckland). Craig Phillips (AgResearch) gave presentations about the programme to the NZ Beekeepers Association AGM in June 2013 (Ashburton), Beef and Lamb New Zealand in April 2014 (Lincoln); and AgResearch in October 2013 and June 2014 (Lincoln).

10. Acknowledgements

We thank the many DOC staff involved who have shown continued dedication, commitment and enthusiasm during a difficult period of restructuring and high workloads. We also acknowledge the many people from outside DOC who have generously provided their time, advice, support and expertise, including researchers in the Better Border Biosecurity research collaboration, www.b3nz.org.

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Appendix 1

Programme costs for 2013/14 financial year (July to June) in New Zealand dollars

Salaries	$139,419
Wages	$903,117
Uniforms	$51,211
Other personnel	$22,556
Total personnel	**$1,116,302**
Travel—domestic, expenses	$14,944
Vehicles	$15,420
Field equipment—purchase	$18,285
Contractors/consultants	$160,469
Printing/publications/education	$35,539
Other operating	$16,949
Total operating	**$261,606**
Total expenses	**$1,377,908**
External contributions*	**$50,000**
DOC expenditure	**$1,327,908**

* External contributions were obtained from Horticulture NZ ($40,000) and Dairy NZ ($10,000). In addition, MPI contributed $76,000 toward research. Therefore the total expenditure for 2013/14 was $1,453,908.

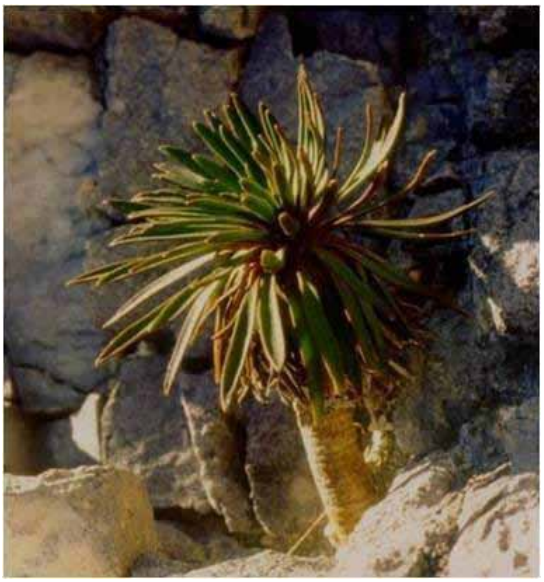
Appendix 2

Six case studies on native cresses at risk from *Pieris brassicae*

Coastal peppercress (*Lepidium banksii*)

- Threat status: Nationally Critical. Endemic to New Zealand.
- Sub-shrub related to the well-known Cook's scurvy grass.
- Total known population less than 150 individuals confined to seven coastal sites in Tasman Bay, Nelson.
- All populations are within 6–60 km of the current area of *P. brassicae* infestation.
- Highly vulnerable to extinction and likely to be the first casualty of *P. brassicae* range expansion.
- Most sites are moderately difficult to access for management being along steep rocky shorelines or on inshore islands.
- One of 10 endemic species of nationally critical *Lepidium*, all of which number less than 250 individuals and/or occupy an area of less than 1 ha.
- Known host of small white butterfly.

Chalk cress (*Pachycladon fasciarium*)



- Threat status: Nationally Critical. Endemic to New Zealand.
- Tap-rooted, long-lived rosette herb.
- Total known population of 37 individuals; rarer than kākāpō.
- Confined to the limestone bluffs of the Chalk Range, South Marlborough.
- Population is within 90 km of current area of *P. brassicae* infestation.
- Site is on private land and bluff habitat is difficult of access and hazardous for management.
- Extremely vulnerable to extinction by *P. brassicae* due to very small population size, infrequent seeding (monocarpic—flowers once and dies), very slow recruitment and limited ability to recover from damage.

But for one Tasmanian species, *Pachycladon* genus is endemic to New Zealand, with most of the ten New Zealand species being regional endemics and 6 being Nationally Threatened/At Risk.

Red Hills penwiper (*Notothlaspi* "Red Hills")

- Threat status: Nationally Critical. Endemic to Nelson.
- Cushion plant with a total known population of less than 200 individuals.
- Highly specialised habitat: confined to the highest peaks on ultramafic rocks of the Red Hills plateau, Nelson.
- All populations are within 45 km of current area of *P. brassicae* infestation.
- Vulnerable to extinction because *P. brassicae* can occupy the alpine zone.
- Alpine site is difficult to manage, due to its inaccessibility and weather constraints.
- The *Notothlaspi* genus is endemic to New Zealand—contains three species, including the well-known penwiper plant of South Island screes.

Mangere Island cress (*Lepidium oblitum*)

- Threat status: Nationally Critical.
- Sub-shrub related to the well-known Cook's scurvy grass.
- Endemic to Mangere Island group of the Chatham Islands.
- Total known population less than 100 individuals confined to two small islands.

- Short-term buffering from *P. brassicae* threat due to distance of Chatham Island from mainland New Zealand, but migration of *P. brassicae* to the Chathams group is inevitable if it becomes established on the mainland because *P. brassicae* have strong migratory behaviour and are good fliers.
- Both known sites are very difficult and expensive to access for management, being isolated and exposed islands.
- One of six species of *Lepidium* found on Chatham Island group, all of which are nationally threatened.
- One of seven species of *Lepidium* which are endemic to New Zealand's remote off-shore islands. All are threatened and six are nationally critical. Most species are very difficult and expensive to access.

Magnesite bittercress (*Cardamine* "Cobb magnesite")

- Threat status: Nationally Critical.
- Small colonial rosette herb endemic to nationally rare talc-magnesite outcrops in Cobb Valley, NW Nelson.
- Total known population estimate of less than 1500 individuals on five outcrops, all within 1 km of each other and occupying a habitat of less than 1 ha extent.
- All populations are within 50 km of current area of *P. brassicae* infestation.

- Other species of bittercress in New Zealand are known small white butterfly hosts and *Cardamine* is a known host genus for *P. brassicae* internationally.
- Four of the five sites are relatively easily accessible, being close to vehicular access.
- An example of c. 42 species of native bittercress, the largest cress genus in New Zealand; more than all the other native species put together.
- Almost all native bittercress species are endemic. New Zealand species represent 20% of the world's *Cardamine* biodiversity.
- Most native bittercresses are as yet formally undescribed and unranked for threat status, although c. 30 are presumed nationally threatened and c. 22 are highly restricted in their distributions.

Matangoa (*Rorippa divaricata*)

- Threat Status: Nationally Vulnerable; endemic to NewZealand.
- Widespread large, leafy herb, ranging from Northland to northern South Island and Chatham Islands.

- Total known population estimate of less than 5000 individuals within 40 populations and occupying an area of around 100 ha extent.
- Some of the best sites nationally for this species are all within 60 km of the current area of *P. brassicae* infestation.
- Known host of small white butterfly.

Some sites have difficult access for population management including steep, rocky coastlines, lake shorelines, marble bluffs and offshore islands.

Appendix 3

Pieris brassicae detection data for spring 2013 and 2014

For each month, Table A3.1 shows the number of inspections that detected each life stage; in every case the number was lower for 2014 than in 2013. The total number of inspections and detection rates for each life stage are also shown; these also declined in every case, typically by about 90%. Nelson properties were found to be infested with *P. brassicae* during 743 inspections in spring 2013, but only during 141 inspections in spring 2014.

Figure A3.1 (next page) shows the locations where *P. brassicae* was present and absent in spring 2013 and 2014. Compared to spring 2013, the extent of *P. brassicae*'s distribution to the north of Nelson declined in spring 2014, though its distribution to the south and east was similar. In spring 2013, *P. brassicae* was detected up to 6.9 km from Port Nelson with a mean (± SD) of 1.5 ± 1.4 km and, in spring 2014 (to 26 November), it was detected up to 6.8 km from Port Nelson with a mean (± SD) of 1.7 ± 1.3 km.

The distribution of *P. brassicae* also became more patchy. In spring 2013, *P. brassicae* was detected in 33 of 45 (73%) management blocks and, in spring 2014 (to 26 November), it was detected in 23 of 45 (49%) blocks. (These figures include detections of all *P. brassicae* life stages.)

Table A3.1. A brief update on detections of *Pieris brassicae* adults, eggs and larvae for spring 2014, with data from spring 2013 also provided for comparison.

YEAR	MONTH	ADULTS	EGGS	LARVAE	INSPECTIONS	DETECTION RATE ADULTS	DETECTION RATE EGGS	DETECTION RATE LARVAE
2013	Sep	71	174	29	2991	0.024	0.058	0.010
	Oct	29	145	183	8027	0.004	0.018	0.023
	Nov	20	59	122	7956	0.025	0.007	0.015
2014	Sep	44	24	5	6484	0.007	0.004	0.001
	Oct	18	24	28	9380	0.002	0.003	0.003
	Nov*	3	0	12	8758	0.0003	0.000	0.001

*To 26 November 2014

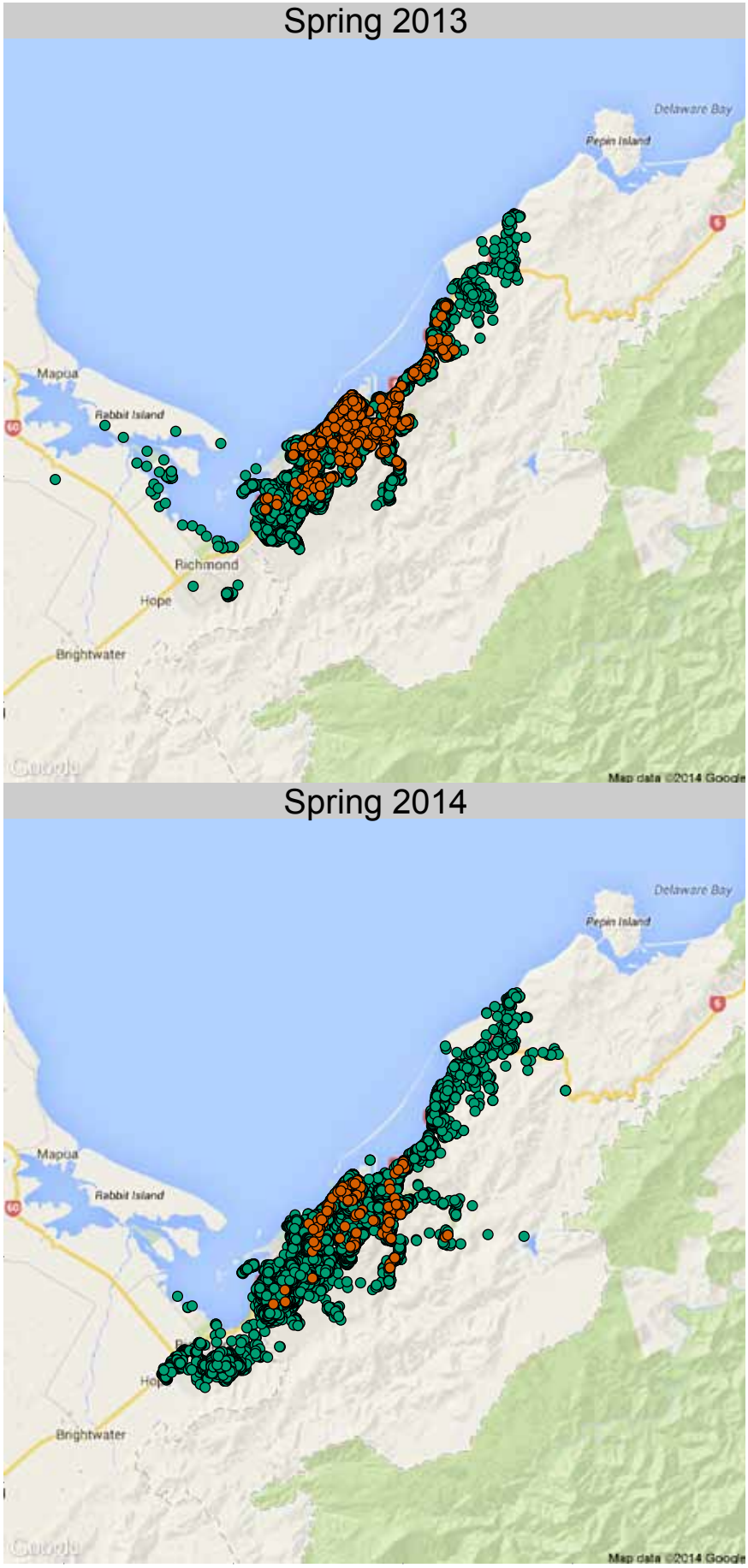
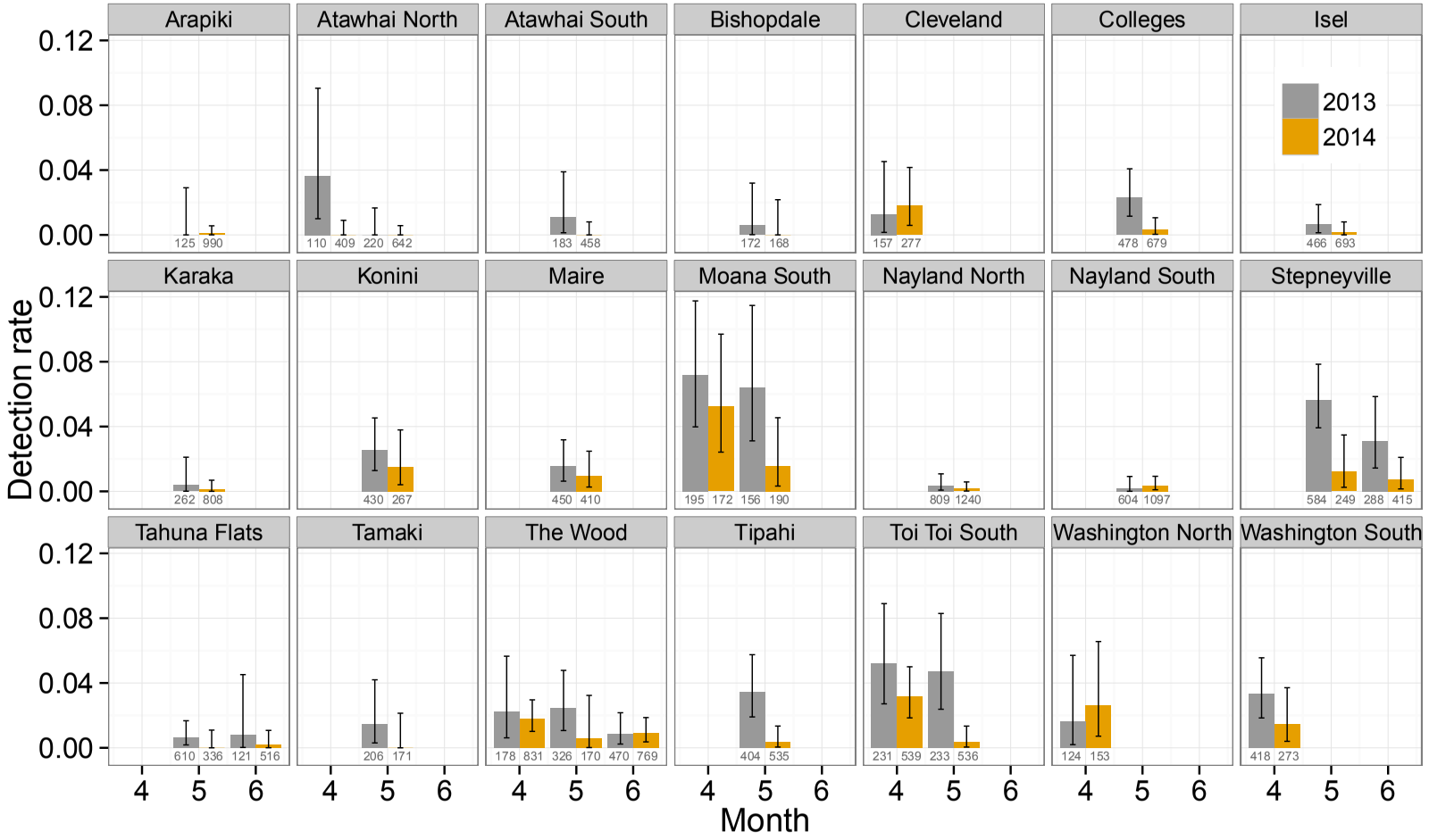


Figure A3.1. Spatial distribution of *Pieris brassicae* presence (red) and absence (green) records within the Nelson eradication zone in spring 2013 and 2014.

Appendix 4

Pieris brassicae detection rates from general surveillance conducted April to June in 2013 and 2014



* Only includes blocks searched in the same month in both years. Number of inspections shown on top of each bar.

Figure A4.1. *Pieris brassicae* detection rates from general surveillance conducted April to June in 2013 and 2014*. Error bars show 95% confidence intervals.

Appendix 5

Pieris brassicae public awareness activities August 2013 to July 2014

TIMING	ACTIVITY	COMMENT
12 September 2013	Media release announcing the spring emergence of adults, requesting the public to search for *P. brassicae* and report any finds.	Coverage in Nelson Mail and local newspapers
25 September	Media release announcing the *P. brassicae* bounty hunt due to start over the school holidays (30 Sep – 11 Oct).	Coverage in Nelson Mail and local newspapers
25 September	Bounty hunt information sent out via DOC Facebook page to youth organisations.	
25 September	Bounty hunt news article with the Hon. Nick Smith and some local school children features on TVNZ news.	Article also picked up by national and local radio and newspapers
30 September	Bounty hunt bill stickers posted in Nelson CBD over the hunt period.	
30 September	Bounty hunt ad shown at Nelson State cinema over the hunt period.	Information about the hunt was also available in the cinema foyer for people to collect.
7 October	Media release—update on how the bounty hunt was progressing.	Coverage in Nelson Mail and local newspapers
14 October	Media release reviewing the bounty hunt success and a thank you to the public for their involvement.	Coverage in Nelson Mail and local newspapers
29 October	Newspaper ad in the Nelson Weekly's pest control feature.	
October	New *P. brassicae* information leaflets and fridge magnets produced.	
October	New updated *P. brassicae* ID sheet produced.	The fact sheet compares *P. brassicae* with *P. rapae*.
30 October	Nelson Farmers Market and Nelson Saturday Market seedling and vegetable stall holders visited and given *P. brassicae* information.	
11 November	Media release—asking public to check campervans, caravans and trailers for *P. brassicae* pupae before leaving Nelson for summer holidays.	Coverage in Nelson Mail and local newspapers, information also included in AA and NZMA newsletters and websites.
12 November	VTNZ and VINZ and AA WOF stations visited by DOC staff.	Staff at VINZ and VTNZ trained in pupae searching on vehicles coming in for WOFs. All WOF stations and AA given information about *P. brassicae*.
17 November	Display at the Nelson Growables Fair.	
23 – 24 November	*P. brassicae* display at the Heslops Motor Home Show	Display focused on checking campers, caravans and trailers for pupae.
7 – 8 December	Information leaflets and magnets distributed to all households in the Nelson and Richmond area.	PMP Distribution was contracted to distribute material.
December	*P. brassicae* pages on the DOC website updated and a host plant page added.	
13 December	Media release asking the public to refrain from moving vegetable scraps, brassica vegetables and seedlings out of Nelson, or check them first.	Coverage in Nelson Mail and local newspapers.
17 January 2014	Thank you cards sent out to frequently visited properties, and properties that had data loggers/traps on etc.	

Continued on next page

Appendix 4 continued

TIMING	ACTIVITY	COMMENT
28 January	Butterfly newsletter, issue 12, sent out to stakeholders.	
February	Host plant garden set up with signage at the Waimarama Community Gardens.	
16 – 17 February	Information leaflets and magnets distributed to all households in outlier sites.	PMP Distribution was contracted to distribute material.
9 March	*P. brassicae* display at the Nelson Race Unity Day	This display was designed to connect with the refugee community in the Nelson area.
14 April	Media release and article in the Nelson Mail gardening section regarding winter cover crops.	Asking Nelson Tasman residents to refrain from planting mustard as a cover crop.
14 April	Information regarding cover crops given to Mitre 10 Mega, Bunning's and the Wharehouse to display in their gardening sections.	
14 April – 5 May	Autumn campaign. Communication used: • Radio ad on More FM, The Edge, The Sound and the Breeze and interviews with the *P. brassicae* project manager. • Newspaper ad in the Nelson Mail and Nelson and Tasman Leader newspapers. • Media releases at the start and end of campaign. • E news sent out to local stakeholders. • Nelson Saturday market display.	Asking for Nelson Tasman residents help during the *P. brassicae* autumn breeding surge; to search for eggs and caterpillars and report any finds to the MPI hotline. CB Marketing was contracted to help with this campaign, giving advice on communication methods etc.
19 May	Reminder to WOF stations to check for pupae on vehicles over winter months.	
21 May, 6 and 9 June	*P. brassicae* information talks to NMIT English language classes, Victory School Adult Education Classes and English Language Partners classes.	To engage the refugee community who are keen gardeners and to help them feel comfortable with DOC staff entering their properties.
June	Engaged a Nepali and a Burmese interpreter to carry out contract work as and when needed.	Interpreters will be called on when needed to assist field staff to communicate to residents about checking gardens and spraying plants if need be.