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Australia

Final Report

Investigation into the possible recent incursion of an insecticide-resistant biotype of green peach aphid into Australia

Owain Edwards
CSIRO Biosecurity Flagship

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Level 8, 1 Chifley Square
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Tel: (02) 8295 2300
Fax: (02) 8295 2399

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Summary

The green peach aphid (GPA, *Myzus persicae*) is a cosmopolitan pest of oilseeds and vegetables, causing damage both by direct feeding and by transmitting a large number of plant viruses. It is renowned for having developed resistance to more classes of insecticides than any other insect pest. Resistance to the carbamate insecticide pirimicarb was detected in Australian GPA for the first time in 2011. Surveys in 2012-2013 showed this resistance to be widespread across Australia, and that the carbamate resistant aphids were also resistant to synthetic pyrethroids (SPs). The main aim of this project was to conduct genome-wide genetic analyses on Australian and international populations of GPA to determine whether these dual-resistant GPA arose locally in response to insecticide pressures or, alternatively, that they arrived in Australia via a recent incursion.

More than 100 populations of GPA were obtained from all states in Australia, in addition to 19 populations from China and 30 populations from 5 countries in Europe. Over 2500 individual aphids from these collections were tested for the presence of seven resistance mechanisms. Of these, five were detected in Australia and the additional two were found only in overseas populations. The major difference between Australian and overseas populations was the absence of high level, target site resistance to neonicotinoid insecticides in Australia. The new carbamate/SP resistant GPA now widespread in Australia was identified in samples from the UK, Greece, France, and from all but one population in China.

Over 75% of the aphids collected in Australia belonged to one of three genetically identical dual-resistant clones, none of which were related genetically to aphid clones previously present in Australia. One of these clones was an exact genetic match to a sample from Wuhan province in China but not to any populations in Europe, providing strong evidence that this clone dominating GPA populations in Queensland arrived in Australia as an incursion from China. No exact match of the other two dominant clones was found in the European and Chinese samples, but one was related genetically to a dominant European clone.

With resistance to organophosphates, pyrethroids, and carbamates now widespread across Australian populations of GPA, a future incursion of GPA with target site resistance to neonicotinoids (including sulfoxaflor) now prevalent in China and southern Europe would leave Australian oilseed and vegetable growers with virtually no options remaining for GPA control. An economic analysis has estimated an increase of at least 10% in production costs of canola ($34-$39/ha), and a potential economic impact of $542M/yr. Additional research should be conducted to further clarify the gap in Australia's quarantine system that has led to these GPA incursions, and the horticulture industry should aim to close this gap before incursions of GPA with dangerous neonicotinoid resistance occur.

Keywords

Vegetables, green peach aphid, incursion, insecticide resistance

Introduction

The green peach aphid (GPA, *Myzus persicae*) is a cosmopolitan pest of oilseeds and vegetables, causing damage both by direct feeding and by transmitting a large number of plant viruses. It is renowned for having developed resistance to more classes of insecticides than any other insect pest. Resistance to the carbamate insecticide pirimicarb was detected in Australian GPA for the first time in 2011. Surveys in 2012-2013 showed this resistance to be widespread across Australia (Umina et al. 2014). Pyrethroid resistance increased in frequency in parallel with the rise in carbamate resistance. Preliminary molecular studies identified two resistance mutations new to Australia: a pyrethroid resistance mutation (M918L) in the para-sodium channel gene, and a MACE (modified acetylcholinesterase) mutation conferring pirimicarb resistance. GPA with the same combination of resistance alleles was also spreading across Europe (Roy et al. 2013).

With these newly identified resistance mutations, there are four confirmed molecular mechanisms of insecticide resistance in GPA in Australia: One amplified esterase (organophosphates), two kdr parasodium channel resistance mutations (synthetic pyrethroids), and the modified acetylcholinesterase (MACE) mutation (pirimicarb). Because of this existing resistance, vegetable and oilseed growers in Australia are heavily reliant on neonicotinoid insecticides (eg. Imidacloprid) and, most recently, sulfoxaflor for GPA control. There is some evidence for increasing tolerance to imidacloprid in Australian GPA (Umina et al. 2014), but not resistance to field rates. A target site mutation conferring high level resistance to neonicotinoids and sulfoxaflor has been identified in southern France (Bass et al. 2010), but to date it has not been reported except in areas where resistance would be expected to spread from the French source population. If GPA with this resistance mechanism were to enter Australia, many vegetable and oilseed growers would find themselves with no options remaining to control this pest.

The FAO International Plant Protection Convention (IPPC) defines a *plant pest* as "any **species, strain, or biotype** of plant, animal, or pathogenic agent injurious to plants or plant products" and a *quarantine pest* as "a plant pest of potential economic importance to the area endangered thereby and not present there …". Within these definitions, insecticide-resistant strains/biotypes could be the subject of quarantine restrictions. In Australia, quarantine strategies have been implemented to protect against strains/pathotypes of pathogens present overseas (eg. Citrus scab, citrus canker), even if the species itself is already present in Australia. Plant Health Australia (PHA) does recognise the dangers posed by exotic, invasive strains of the Asian honey bee. However, no quarantine strategies have been implemented in Australia against strains/biotypes of any insect plant pests. Many pest species that have been introduced into Australia have evolved insecticide resistance mechanisms not yet present in Australia. Some of these, including GPA, may have an increased risk of entering Australia after recent changes allowing exemptions to fumigation of imported cut flowers (http://www.agriculture.gov.au/import/industry-advice/ian/12/97-2012). Hence, this study into potential incursions of insecticide-resistant GPA provides an important opportunity to raise the profile and consider the implications of the concept of "genes of Biosecurity significance", in contrast to the current focus only on pest species.

Methodology

Collection of *M. persicae* populations within Australia and globally

Collections of GPA in Australia were achieved primarily through linkages and funding arising from other GRDC and Hort Innovation projects. A total of 110 populations were collected representing all Australian states with the assistance of entomologists from SARDI, NSW DPI, QLF DAFF, and DAFWA. These populations were collected across major horticultural, grains, and cut-flower production regions, from both crop and weed hosts. Individuals from all populations were stored separately in vials with 100% ethanol, with collection and plant host details recorded.

The overseas populations targeted for sampling were selected based on identified possible invasion pathways of GPA into Australia. Cut flower imports were considered to be the most likely pathway of entry because (1) many cut flowers are suitable hosts for GPA, (2) GPA can be cryptic and difficult to observe when feeding on cut flowers, and (3) many cut flowers are imported from countries where GPA (and GPA insecticide resistance) are prevalent. Though many cut flowers, in particular roses, are imported from Africa, in particular Kenya, this was not considered a likely source of GPA into Australia because the climate is not conducive for GPA survival. Instead, overseas sampling was targeted towards Europe and China.

European populations were sourced from two sources. Martin Williamson and Chris Bass from Rothamsted Research (UK) provided 10 samples of resistant GPA populations sourced from the UK, Portugal, Spain, Italy and Greece. Jean-Christophe Simon at INRA (France) provided 20 samples of GPA from across France. Samples in China were sourced through a collaborator, Feng Cui, at the Chinese Academy of Sciences, Institute of Zoology, in Beijing. A total of 29 GPA populations were obtained from various locations in China.

Understanding the genetic make-up of *M. persicae* populations

All of the populations were characterized genetically using two approaches. First, individual aphids were tested for the presence of known molecular mechanisms of resistance in GPA (Anstead et al. 2007; Bass et al. 2011; Fuentes-Contreras et al. 2013; Puinean et al. 2010; Puinean et al. 2013). Secondly, individuals from each population were analysed using a set of up to 35 microsatellite loci.

A total of 1500 individuals were analysed from the Australian populations for resistance alleles against four insecticide classes: synthetic pyrethroids, carbamates, neonicotinoids, and organophosphates. All these Australian GPA were analysed for the presence of four mechanisms known from previous screening to be present in Australia (2 X kdr, MACE, esterase) in order to assess the frequency and distribution of these resistance mechanisms in Australia. Individuals representing 30 of these populations representing all states of Australia were analysed for the presence of three additional resistance alleles present overseas but not yet identified in Australia (s-kdr, P450 and target site resistance to neonics). Over 1000 individuals sampled from all the overseas populations were analysed for all seven resistance alleles.

The original research plan was to use 10 microsatellite loci to conduct an initial genetic characterization of the GPA individuals from Australia and overseas, then to follow this with a genome-wide RADSeq analysis. Because of the clonal reproduction in GPA, the microsatellite analysis was found to be sufficient to resolve the genetic differences amongst the Australian and overseas populations.

Consequently, it was decided to increase the number of microsatellite loci to 35 rather than invest in the more expensive RADSeq technology, which allowed many more individual aphids to be tested using the microsatellite and resistance markers.

Economic analysis

The economic impacts from an incursion of insecticide-resistant GPA were estimated, based on estimating the reduced output through yield and quality loss, and the increased pest control costs due to resistance. The economic analysis was conducted by combining a partial budget analysis, a gross margin analysis, and a cost-benefit analysis (CBA) to give an estimate of the potential economic impact of GPA on crop production in Australia. The focus of the initial economic analysis was on oilseed and pulse crops in the grains industry, because of the availability of GPA impact data. Unfortunately, there is little published information on GPA impacts on vegetables in Australia.

The net present value (NPV) of the economic impacts of GPA was projected over a 10 year period. A preliminary CBA and a benefit:cost ratio (BCR) was estimated for preventing new incursions of resistant GPA over this period.

Outputs

1. *An analysis of the genetic relationship between GPA carrying the MACE/M918L combination of resistance alleles in Australia and overseas.* This analysis has shown that GPA individuals with the MACE/M918L alleles are widespread in Australia, representing over 80% of all aphids collected. The majority of these (75% of all collected aphids) were members of one of three dominant "superclones" now dominating the Australian agricultural landscape, named superclones A, B, & C (Fig. 1). Only superclone A was found in WA, while superclone C was most frequent in QLD. Populations in southeastern Australia including Tasmania showed a mixture of all three superclones (Fig. 4). The samples from Europe and China had a complex mixture of resistance genotypes, including MACE/M918L genotypes in the UK, France, Greece, and China. Indeed, the MACE/M918L genotype was found at every sampled location in China except Yunnan province (Fig. 2). The GPA MACE/M918L genotypes now in Australia show a greater level of genetic similarity to MACE/M918L genotypes overseas than to other GPA genotypes in Australia (Fig. 3) – supporting the hypothesis that they have entered Australia via a recent incursion. **NOTE: Genetic analyses of French GPA are ongoing, which may affect this output. If so, the output will be amended to include the additional information.**

2. *An assessment as to whether the recent detection of Australian populations of GPA carrying the MACE/M918L resistance allele combination is the result of a contemporary incursion from overseas.* An exact genetic match based on 35 microsatellite loci was found for superclone C in the sample from Wuhan province in China (Fig. 5). This was surprising considering the limited sampling that was conducted in China for this project, and suggests that this clone is probably widespread across landscapes in China as well. No exact genetic matches to superclones A and B were found, but again this is not surprising considering the limited sample sizes in this project. Superclone B shares half its alleles with European Clone O, which also has the MACE/918L resistance genotype. This may indicate that these two clones have a common ancestor.

Superclone A is in the same genetic clade as superclone B, which could suggest it may also have a Chinese origin. **NOTE: Genetic analyses of French GPA are ongoing, which may affect this output. If so, the output will be amended to include the additional information.**

3. *A summary of possible invasion pathways for GPA into Australia*. One invasion pathway of superclone C from China to Australia has strong support in the genetic data. This superclone was the dominant clone collected in QLD, but was also present at a lower frequency in Victorian samples. This may indicate that the port of entry into Australia was in Queensland. However, it is also possible that superclone C is dominant in QLD because it is adapted to a warmer climate similar to that of Wuhan province in China, where it was collected. Additional sampling is planned from China to test this hypothesis. The genetic diversity of MACE/M918L genotypes discovered in Australia (3 superclones & 25 lower frequency genotypes) indicates that the gap in the Australian quarantine system allowing invasion of these resistant GPA is significant. **NOTE: Genetic analyses of French GPA are ongoing, which may affect this output. If so, the output will be amended to include the additional information.**

4. *Economic analysis of impact of an insecticide-resistant GPA*. An economic analysis of the costs of the recent incursion of dual-resistant GPA genotypes in grains estimates an increase in production costs of approximately $35-$39/ha, equivalent to about 10% of total production costs. This data is based on availability of other insecticide options such as sulfoxaflor. It should be noted that a future incursion of GPA with target site neonicotinoid resistance would leave most growers with no available (affordable) insecticide options for GPA control. **NOTE: A similar analysis is being conducted for vegetables, but the available data is not robust. Depending on the quality of the results, this output may be amended to include the additional information.**

5. *Submission of at least one scientific paper to a peer reviewed scientific journal.* A publication describing the complete results of this study is currently in preparation, awaiting the final analysis of the French samples. It is anticipated that the manuscript entitled "Evidence for a recent incursion of insecticide-resistant genotypes of the green peach aphid, *Myzus persicae*, into Australia" will be submitted in July 2016.

Outcomes

1. *Evidence as to whether regulatory processes should more actively consider the threat posed by damaging genotypes of an insect species that already occurs in Australia.* This project has provided strong evidence that additional damaging genotypes of GPA, a species already present in Australia, have recently entered Australia through a gap in the quarantine system. The consequence of these incursions have been demonstrable, with the new genotypes now dominating GPA populations across Australia – and impacting on farming practices in both horticulture and grains. Equally important is the consideration that additional clones with neonicotinoid resistance could enter via the same pathway, which would leave many growers with no remaining insecticide options for GPA control. At the moment, only low level metabolic resistance to neonicotinoids has been identified in Australia. The results of this project were presented twice to the Department of Agriculture and Water Resources, first in May 2015 in an

invited presentation to the DAWR Science Exchange in Canberra. In March 2016, a meeting was held with the science leadership at DAWR to argue the case for a "Genes of Biosecurity Significance" strategy.

2. *An economic assessment of the potential impact of the new resistance that will enable industry to assess the potential for harm and the level of priority this new detection should be given.* The total economic impact of a new GPA resistance to the grains industry alone has been estimated at $542M/year. This does not include the economic impacts in horticulture, which have been more difficult to estimate because of the lack of available data. It is of course too late to prevent the impact of the MACE/M918L genotypes, which already dominate the Australian agricultural landscape. It is the case that high level (target site) resistance to neonicotinoids was not found in Australia, but was found in the samples obtained from France and China. The economic impacts estimated here are equally, and perhaps even more relevant to a future incursion of a neonicotinoid resistant genotype. **NOTE: A similar analysis is being conducted for vegetables, but the available data is not robust. Depending on the quality of the results, this outcome may be amended to include the additional information.**

Evaluation and Discussion

The methodology used in this project has been very effective in addressing the overall aims. The decision to prioritise overseas populations by first assessing likely pathways turned out to be well founded. Published information was readily available pointing to Europe and China as likely source populations for the dual resistant GPA genotypes, and the genetic analyses have added further evidence to this. This points to the importance of being fully cognizant of all relevant information before deciding on a research plan.

The decision to focus on microsatellite markers rather than develop RADSeq genome-wide markers also turned out to be a good one. The fact that no additional GPA genotypes were identified with 35 microsatellite markers compared to the 10 originally used indicates that expanding to 10,000 markers or more using RADSeq would have provided very little additional value. Considerable effort and resourcing would have been required to develop the RADSeq markers, which was instead available to analyse more individual samples. In contrast, RADSeq markers would have been essential if the target organism had been sexually reproducing, in order to deal with the complexity arising from mixing of genotypes each generation. It is clearly important to select the most appropriate methodology for the system under study.

There were delays in the delivery of project milestones, almost exclusively due to delays in obtaining samples from overseas partners. Most of these delays were administrative rather than scientific, with the longest delays arising from our French collaborators wanting a Material Transfer Agreement in place before sharing samples. This will be considered in the planning of future projects.

The value of the economic analysis conducted in this project was highly dependent on information being available on the economic impacts and insecticide usage against GPA. This information was available for

GPA in oilseeds only because of a consultancy that was resourced by GRDC in the immediate aftermath of the problems growers in South Australia and Victoria were facing with controlling GPA in canola in 2014. Equivalent information was not available for GPA impacts in vegetables. More broadly, it is a problem in Australia that records of insecticide usage in most crops are not readily available, if only to be able to monitor practice change. This information is available for cotton, only because the cotton industry purchases the information from private providers to make it available to stakeholders.

Finally, the major barrier to achieving the intended outcomes of this project has been in translating the outputs into outcomes. This was not a problem with the quality of the outputs, which were far more robust and convincing than was anticipated, and fully supported the hypothesis upon which the project was designed. There was also no problem with communicating the outputs, as we were given two opportunities to present our results to key decision makers at DAWR. The major barrier to achieving the desired outcome is one of politics: policy makers must consider issues other than the scientific evidence when making decisions that affect trade.

Recommendations

1. Additional research is required to provide stronger evidence linking these GPA incursions (and potentially other pest incursions) to the decision to allow exemptions to the fumigation requirements for imported cut flowers. If this is indeed resulting in a gap in our effective quarantine system, then the horticulture industry should attempt to address the problem. It may be that blocking imports from countries like China may be politically inexpedient, but these fumigation exemptions have more likely resulted from the lobbying of major Australian retailers in order to increase shelf life.
2. If preventing future incursions through policy change is not possible, then it will be increasingly important to understand incursion pathways and what resistance issues are likely to arise from future incursions. These will need to be considered as part of future resistance management strategies.

Scientific Refereed Publications

Journal article in preparation

Edwards OR, Weeks AR, Umina PA. in prep. Evidence for recent incursions of insecticide resistant green peach aphid, *Myzus persicae*, into Australia. *Molecular Ecology*

Intellectual Property/Commercialisation

No commercial IP generated

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Australian GPA collections and all molecular analyses in this project were conducted by Paul Umina and Andrew Weeks at cesar.

Appendices

Appendix 1: Figures referred to in final report. **NOTE: Additional genetic analysis of French populations will likely result in amendments to these figures, as well as additional figures. This additional information will be added when available.**

Appendix 2: Additional methodological information on the economic analysis. **NOTE: Additional information may be added when the economic analysis of GPA impacts on horticultural crops is completed.**

Figure 1. Green peach aphid Pyrethroid/Carbamate resistant clone(s) 2014 -2015

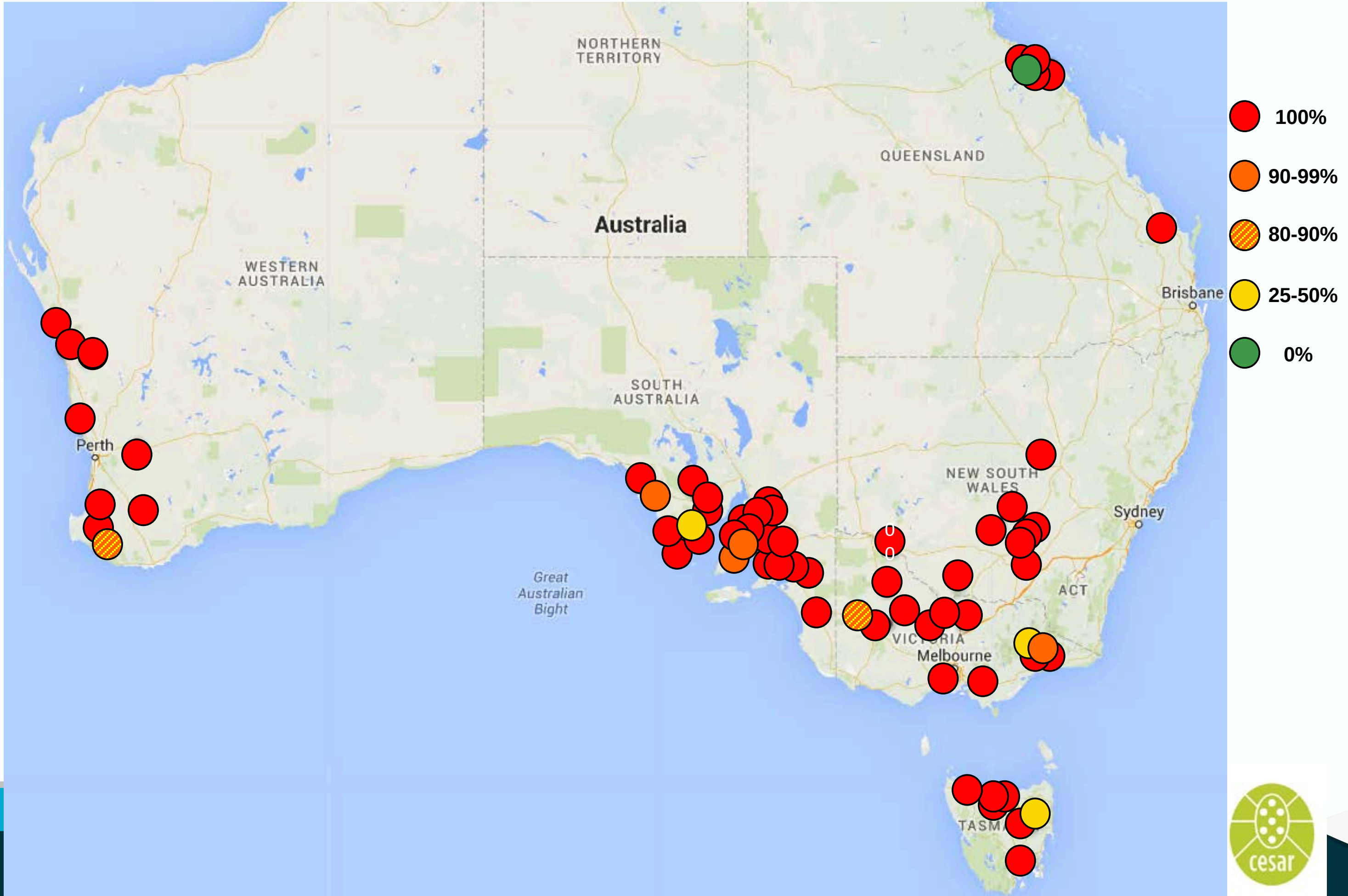
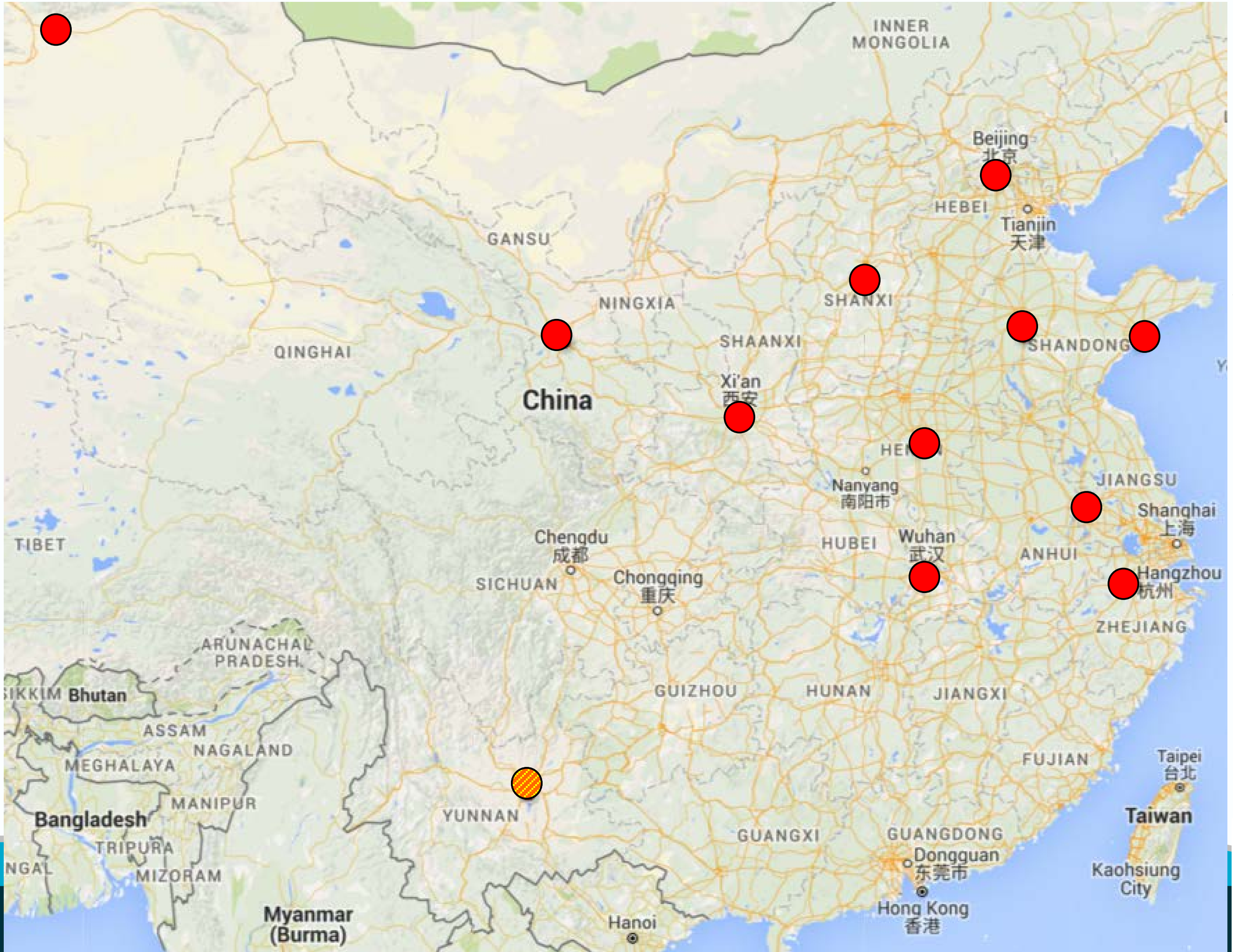


Figure 2. Pyrethroid/Carbamate resistant clone(s) from China 2015

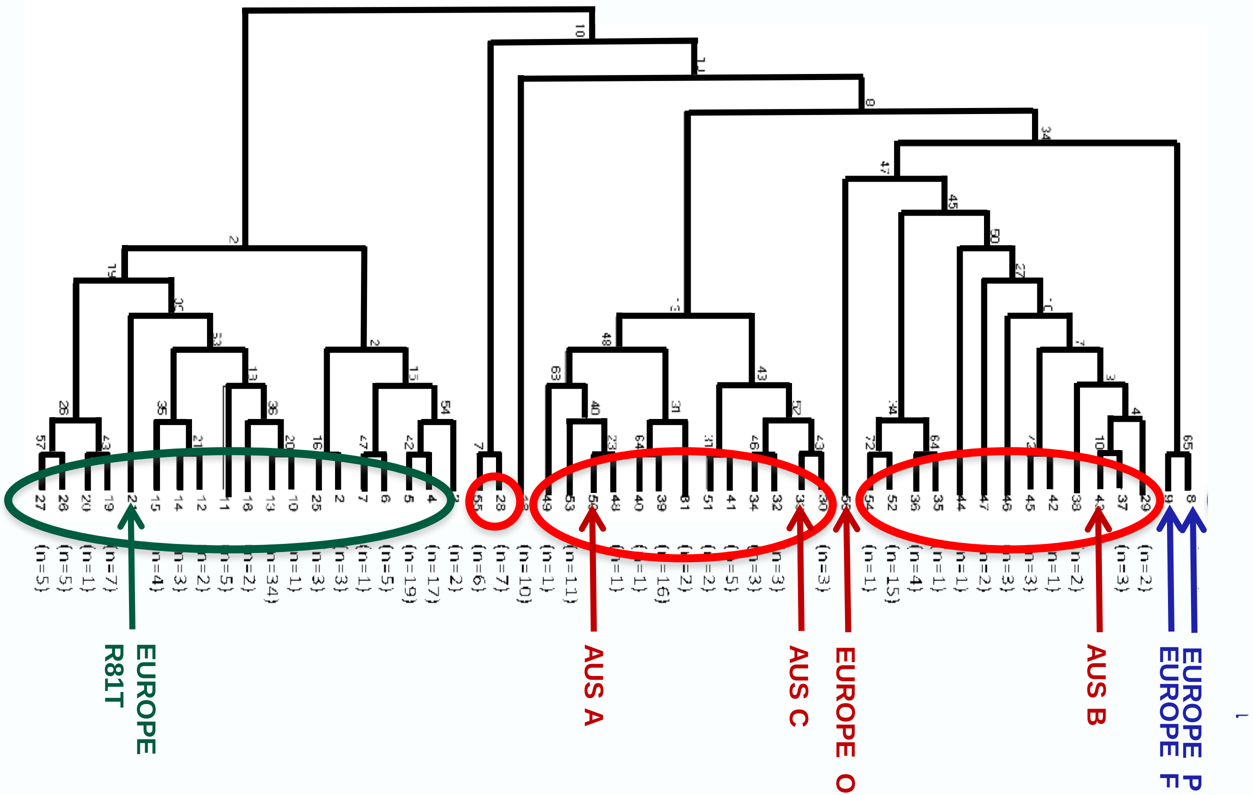


Pyrethroid & Carbamate Resistance
🔴

Carbamate Resistance
▨

Susceptible
🟢

Figure 3. Microsatellite analysis of Australia *M. persicae* populations including related clones from Europe.



Green - susceptible
Blue – pyrethroids
Red – pyrethroids & carbamate

Figure 4. Distribution of Australian *M. persicae* superclones 2014 -2015

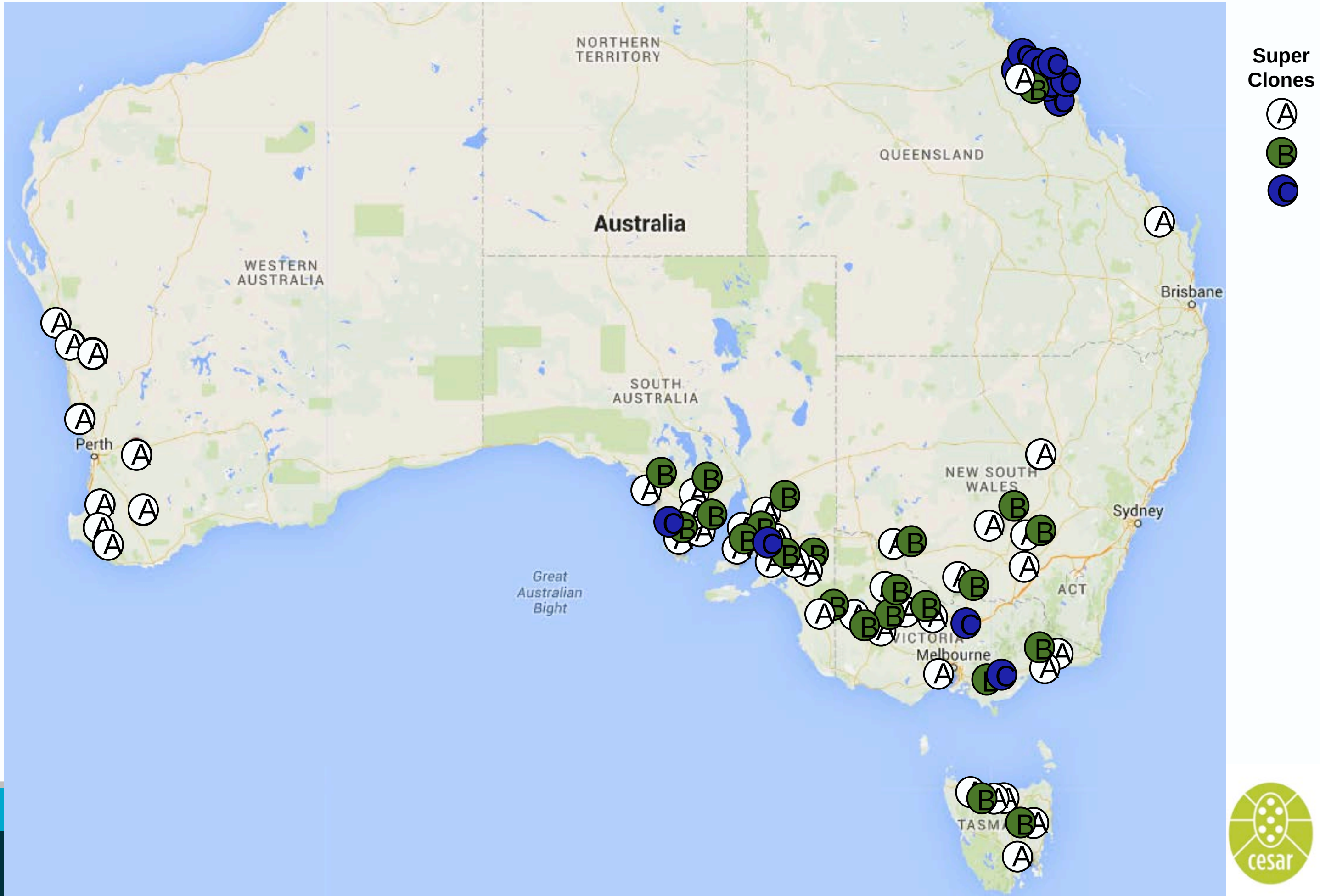


Figure 5. Location of Australian *M. persicae* superclone C collected in China 2015

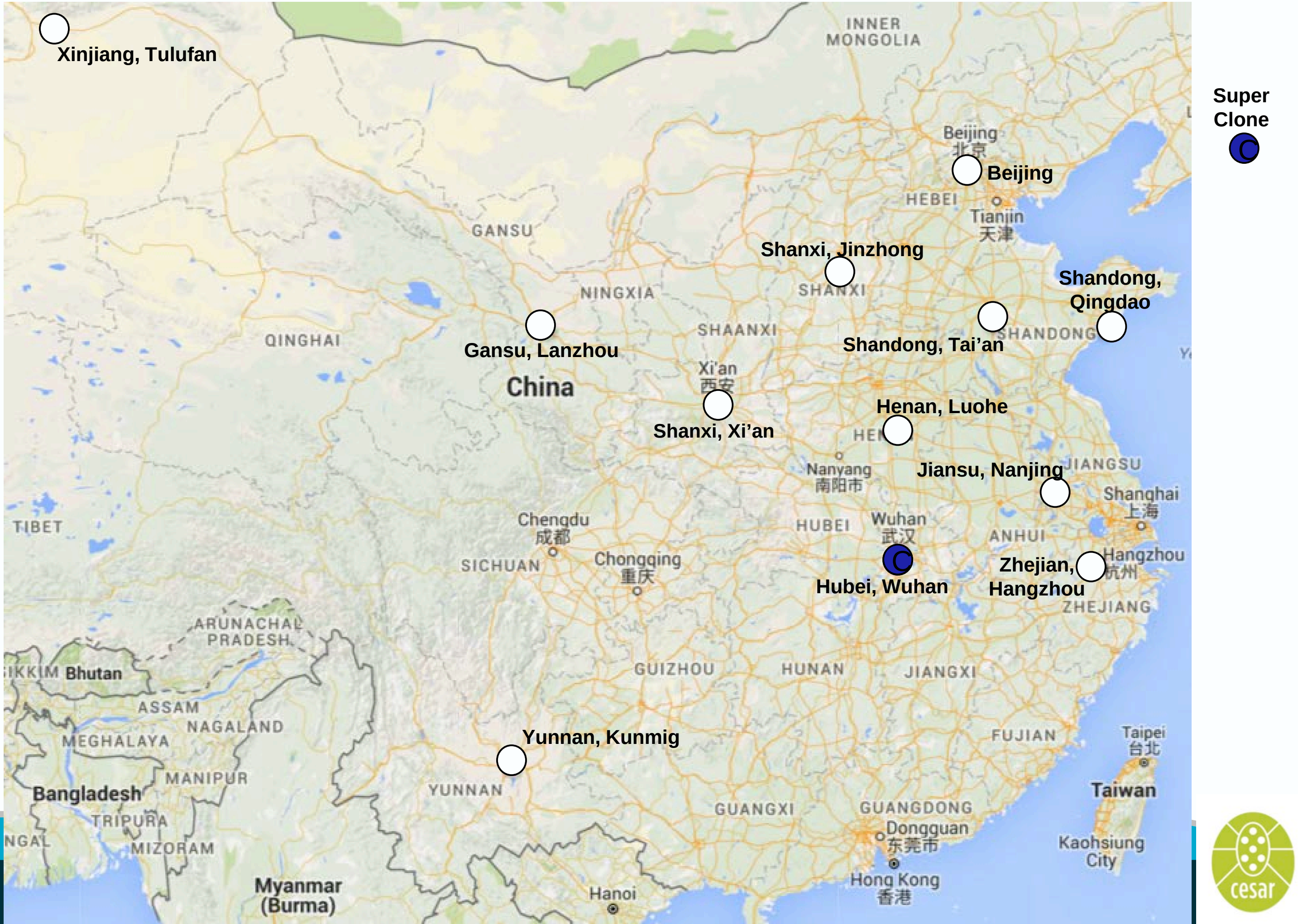
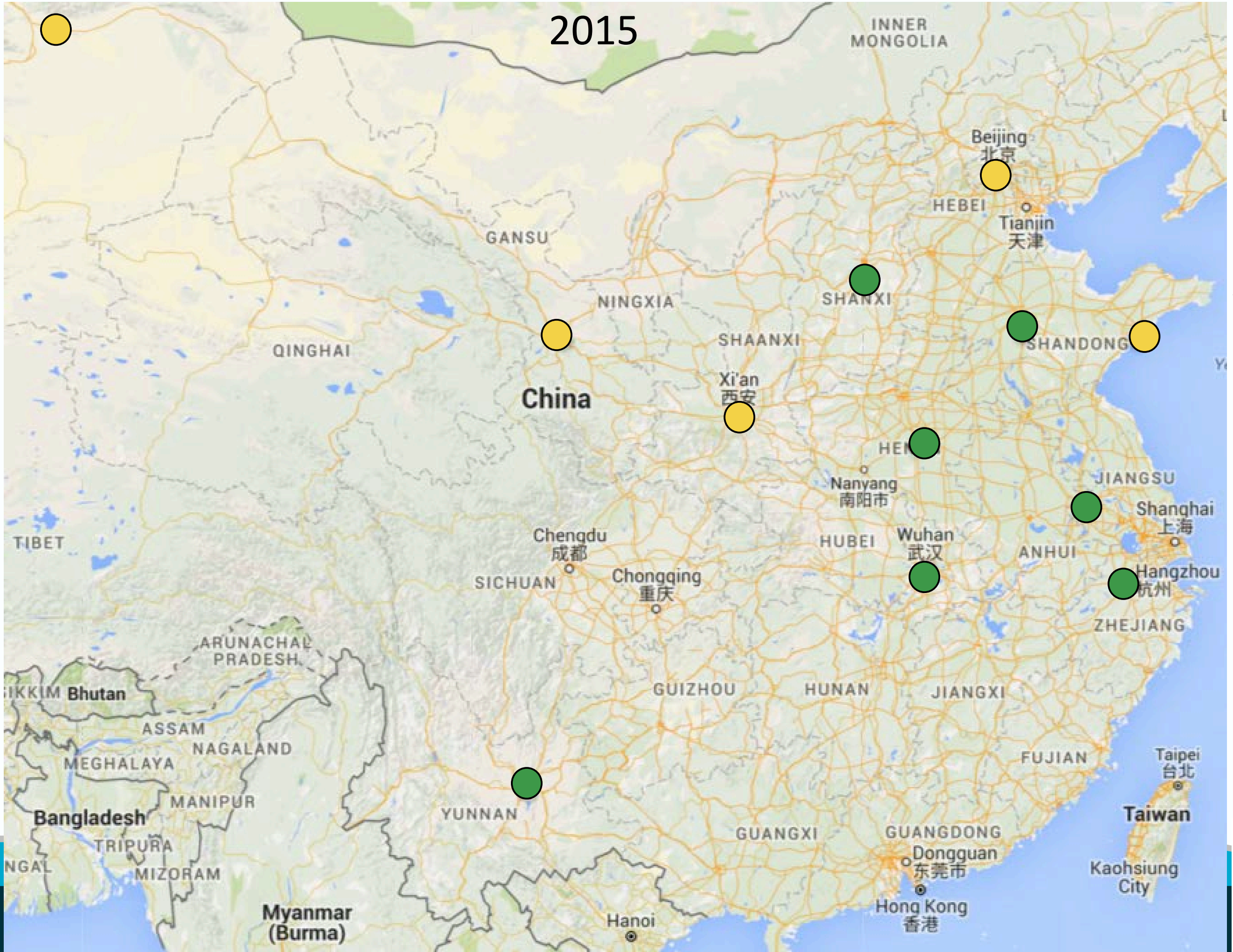


Figure 6. Locations of neonicotinoid resistant *M. persicae* clone(s) from China in 2015



Neonic. Resistance

●

Susceptible

●

5.1 Cost-benefit analysis

5.1.1 Potential impact of *M. persicae*

A good starting point is to calculate the potential damage and the current cost of control measures against the GPA. The pest has a wide range of host but the main impacts of the GPA relate to virus transmission impacts rather than direct feeding effects. In Australia, the main impacts are on canola and other oilseeds via beet western yellow virus (BWYV) transmission, cucumber mosaic virus in lupins in Western Australia and a suite of viruses it transmits in crucifer vegetables. We don't get much GPA on potatoes in Australia (a different species, potato aphid, is more common). Also, peaches and other stone fruit are attacked by the sexual stage, which is very rare in Australia—and so not worth including in this analysis. Hence the analysis presented here is based on estimates of damage to mainly oilseeds and pulses.

Table 1: Production statistics and value of horticultural crops at risk from the GPA

	2011/12	**2012/13**	**2013/14**	**2014/15**	**Mean**
Canola-area (ha)	2,460,972	3,271,649	2,720,835	2,896,951	2,837,602
Canola-production (t)	3,427,294	4,141,731	3,832,049	3,540,021	3,735,274
Canola-yield (t/ha)	1.4	1.3	1	1.2	1
Canola-value ($m)	1,759.3	2,269.54	2,128.72	1,782.36	1,985
Other oilseeds-area (ha)	73,929	99,703	55,377	54,438	70,862
Other oilseeds-production (t)	100,254	129,432	62,531	74,653	91,718
Other oilseeds-yield (t/ha)	1.4	1.3	1	1.4	1
Other oilseeds-value ($m)	59.7	67.88	37.28	55.81	55

Source: Australian Bureau of Statistics (2016)

Table 1 gives the production and output statistics for these crops in Australia from 2011/12 to 2014/15. Averaged over these four years the total value of the crops at most risk from the GPA is $2.0 billion per year ($1985 million for canola plus $55 million for other oilseeds).

We assume that the 'policy off' option will result in widespread occurrence of the GPA within Australia. The impacts that would result to the industry would be some combination of reduced output through yield and quality loss and increased pest control costs. The increased control costs would be mainly the cost of new chemicals needed to control the GPA (i.e the cost of resistance).

The estimated cost of GPA control in 2015 are summarised below in table 2. It should be noted that sulfoxaflor and pirimicarb were the only chemicals registered for aphids in canola in Australia at the time of conducting this research. According to information provided by DAFWA, sulfoxaflor (transform) was sold to the farmer at a cost of $15.45/hectare for the 100 Ml/ha rate ($3090/20 litres). Pirimicarb costs $15 per hectare for the 500g/ha rate (or $150/5 kg), which drops to $9/ha if the 300g/ha rate is used, which is popular and effective if temperatures are above 20C. There are also other costs involved in early prevention and control of GPA in canola to prevent virus transmission. They include input costs with regards to any seed dressings used.

Therefore the total changes in production costs due to *M. persicae* is approximately $34-$39 per hectare, which is equivalent to about 10% of total production costs of canola (Table 2).

Table 2: partial budget showing changes in production costs due to GPA

	Annual expenditure ($, 2015)
Production costs	
Extra costs of Insecticides	
Sulfoxaflor (transform) (100 Ml/ha)	$15.45
Pirimicarb (300 g/ha-500g/ha)	$9-$15
Dimethoate (500 mL/ha)	-
Alphacypermethrin (400 mL/ha)	-
Total insecticides	$24.45-$30.45
Additional measures	-
Seed dressings	$4.00
Extra labour costs	
Costs of early prevention/control	$4.00
Total measures	$33.45-$38.45
Costs 1 ha/year	$33.45-$38.45

Source: based on data from DAFWA

The literature indicates large economic losses from the GPA. But the quantification of the potential damage of the *GPA* in Australian horticultural production is not attempted in the literature. The approach taken here was to present a range of estimates of potential annual losses from the crops at most risk from the GPA. Table 3 lists the hosts at risk and gives production statistics and estimates of potential GPA economic impact. The potential losses from BWYV were estimated by the GRDC report to be 43% of total yield, similar to the maximum 46% yield loss identified by Jones et al. (2007). Miles and McDonald (2000) estimated that aphids in general cause 10% losses in crop yields. The uncertainty associated with these estimates is high, so we created a range of estimates using a triangular distribution of impacts (mean=27%, maximum=46%, minimum=10%) to underscore a portion of this uncertainty.

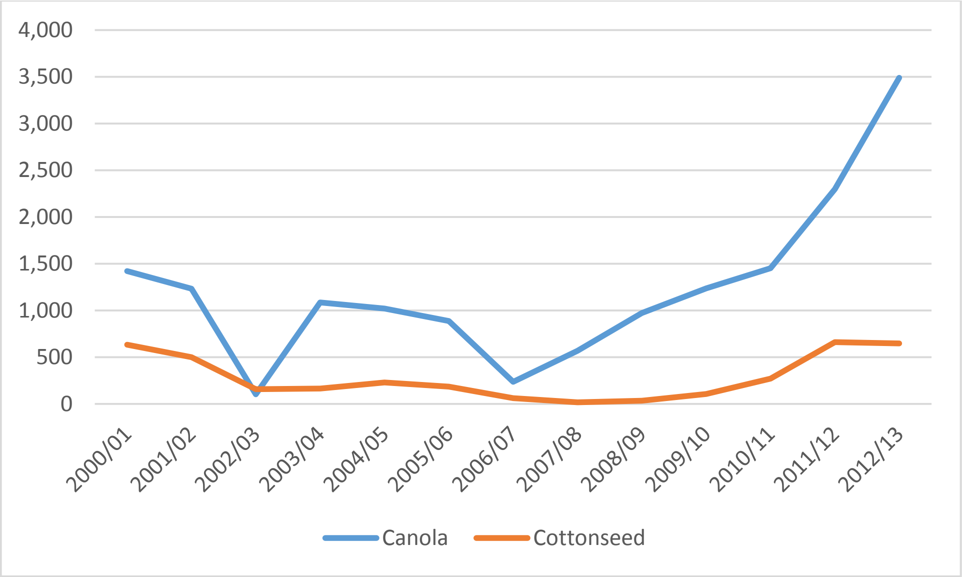
Table 3: Horticultural crops at risk from the GPA: mean annual data for 2011/12-2014/15

Crop	Planted area (ha)	Production (tonnes)	Value ($ million)	Potential loss estimate (%)	Potential losses ($ million)
Canola	2,837,602	3,735,274	1,985	27	536
Other oilseeds	70,862	91,718	55	10	5.5
Pulses					
Lupins					
Crucifer vegetables					
Total					542

Source: Australian Bureau of Statistics (2016)

Global canola production and trade have grown rapidly over the past few years as the demand for canola oil has increased. Australia plays an important role in this trade. The majority of crop production at risk from the GPA is destined for the export market. Figure 1 illustrates the volume and importance of exports for each GPA host industry sector. The European Union and China are the largest export markets for Australian canola. In 2014-15, Australian canola exports to the EU accounted for $550 million, while China bought $311 million out of a total of $1.35 billion in sales (ABARES, 2016).Overall, approximately 73% of canola production with a market value of $1.35 million is destined for exports (ABARES, 2016). We estimate that 10% of this may be at risk from the GPA ($0.13 million per year).

Figure 1: Australian oilseed exports by crop ('000 tonnes)



5.2 Cost-benefit analysis of import restrictions to avoid the insecticide-resistant biotype of GPA

The other issue to be considered is the potential consequence of establishing a biosecurity protocol for GPA that might have as one outcome restrictions on imports from countries like china. This scenario was also investigated using a cost-benefit framework. The CBA follows the approach developed by Costello et al. (2007), in which the avoided or foregone damage from a plant pest incursion represents the benefits. The associated cost of restricting import volumes of host products is the deadweight loss (DWL) in international trade, which can be approximated using the equation below (Costello et al., 2007).

$$DWL_t = \frac{1}{2}\left[\frac{M_t^{\,2}}{\varepsilon}\right] P_t M_t \qquad (1)$$

where: *M* is the percentage restriction in imports liable to carry GPA, ε is the elasticity of import demand and *PM* is the value of imports of GPA host commodities. We assume a hypothetical scenario in which the volume of imports of risky commodities likely to transport GPA from selected exporting countries (e.g. China) are restricted/reduced by a constant percentage each year (e.g. 15%). The analysis is performed on trade pathways that are likely to carry the insecticide resistant GPA biotype to Australia.