Final Report

Improving the biosecurity preparedness of Australian horticulture for the exotic Spotted Wing Drosophila (Drosophila suzukii)

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MT17005

Project:

Improving the biosecurity preparedness of Australian horticulture for the exotic Spotted Wing Drosophila (Drosophila suzukii) MT17005

Disclaimer:

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Content

Summary

The objective of this project was to increase the level of preparedness that Australia's horticultural industries have for an incursion of spotted wing drosophila (*Drosophila suzukii; SWD*). Specifically, this increased preparedness would include an improved ability to monitor for and respond to an incursion, and to have an understanding of pest management options to support production and trade. This preparedness work also involved outreach activities that aimed to increase the level of understanding within horticultural industries about the impact of SWD, the damage it causes, how to identify the pest, how to report, and how establishment of SWD may influence pest management. In delivering against the project, a team was formed comprising Plant Health Australia, **cesar**, and Plant and Food Research New Zealand.

To achieve the project objectives, a range of material was developed. Key outputs from this project include: a report on modelling for spread and establishment of SWD, a report on potential impacts of SWD, a report on modelling potential pathways for entry and spread, a report on the surveillance and quarantine of SWD, a literature review of current international knowledge of SWD and the context surrounding early detection overseas, and a SWD extension pack that includes all outreach material produced during the project. Project outputs and knowledge accumulated during the two-year investigation have been used to help develop the SWD Preparedness Plan and associated promotional summary document, SWD Preparedness Basics. The document has been compiled as a preparedness plan rather than a contingency plan due to acknowledgement that eradication of SWD is likely to be difficult. The Preparedness Plan was reviewed by a variety of stakeholders before finalization (industry, researchers and state government personnel).

Project material is aimed at various audiences including horticultural industries, especially berries, cherries, strawberries, summerfruit and table grapes, and key biosecurity decision makers. To maximise information transfer to industry, the project developed a large amount of industry awareness material and facilitated a variety of engagement opportunities, including a stakeholder workshop and an SWD industry 'roadshow' in key host crop regions. Outreach materials will continue to improve horticultural industries' capacity to identify or triage suspect detections of SWD and avoid the experiences seen overseas where a lack of information available following an incursion has resulted in a lengthy period of inactivity and caused significant crop losses. This project has acted as a central hub for industry to access information on spotted wing drosophila

The project has been successful in achieving its objectives and legacy arrangements for the project have been designed to ensure that the intended outcome of increasing industry preparedness will continue to be realized. Importantly, this project has resulted in development of a unique framework for modelling SWD establishment and movement throughout Australian regions. In addition, this project has demonstrated the significant efficiencies that can be gained by an Australian-New Zealand preparedness partnership approach.

If international experience with SWD is indicative of the risks posed to Australia's horticultural industry, considerable challenges lay ahead to minimise incursions, reduce establishment potential, limit spread, and ensure producers possess the knowledge to quickly and smoothly initiate effective management. Simultaneously, Australia is in the fortunate position to be able to utilise the rapidly accumulating scientific knowledge around this pest that has become available since the pest has emerged as an issue in the United States and Europe. If Australia utilises overseas experiences, through well-designed quarantine, diagnostics, surveillance and management strategies, the impacts of SWD can certainly be mitigated to a large degree.

Keywords

Spotted wing drosophila; preparedness; berry; summerfruit; cherry; table grape; exotic; pest; biosecurity

Introduction

Spotted wing drosophila (*Drosophila suzukii*, SWD) is a significant pest of a range of soft, thin-skinned fruits which has in recent years increased its geographical distribution and economic impact. Affected commodities include blueberries, caneberries (e.g. blackberries, raspberries, loganberries and youngberries), cherries, strawberries, summerfruit, and table grapes. While SWD was first described from Japan in 1931 and is recorded from several countries in Asia, its potential importance as a production pest was only fully realised after incursions into the US in 2008 and Europe in 2010.

In contrast to most Drosophila species, SWD is capable of laying eggs (ovipositing) into ripe and ripening, undamaged fruit. Due to the apparent insignificance of other *Drosophila* as pests in commercial production, initial reports of fruit damage in the US were largely overlooked, allowing the pest to expand its geographical range unchecked. The observed impact of SWD in the US and Europe is highly variable depending on crop and region. Losses as high as 80% have been reported in caneberries, strawberries and cherries, however 20–40% losses are more commonly seen. The damage caused by larvae makes fruit unsaleable.

The objective of this project is to increase the level of preparedness that Australia's horticultural industries have for any incursion of spotted wing drosophila. Specifically, this increased preparedness would include an improved ability to monitor for and respond to any incursion, and to have available pest management options for production and for trade. This preparedness also includes an increased level of understanding within horticultural industries about the impact of SWD, the damage it causes, and how to identify the pest.

This project assembles experts from three organisations (Plant Health Australia [PHA], cesar, Plant and Food Research New Zealand [PFRNZ

Through completion of this project it is intended that horticultural industries, especially berries, cherries, strawberries, summerfruit and table grapes will:

- Understand the potential pathways for SWD to arrive in Australia and become established through an analysis of commercial and non-commercial pathways and invasion processes observed internationally
- Understand the biology of SWD and how it is likely to impact various industries across Australia through a review of pest biology and modelling to predict its likely behaviour in Australia
- Understand the surveillance options available for the early detection of SWD and the reliability of these tools though a review of research in trapping systems overseas
- Understand the measures that can be taken on-farm to minimise the impact of SWD should it arrive in Australia, including a gap-analysis of preferred chemical and non-chemical control options
- Be capable of managing an incursion with minimum impact on domestic and international trade through development of a contingency plan summarising key aspects of biology, detection, tracing and control and with early consideration of effective quarantine measures for trade
- Identify gaps in the knowledge of SWD in Australia that will help to prioritise future investment.

This project aligns with the Strategic Investment Plans for the raspberry and blackberry (Rubus), strawberry, cherry, table grape, and summerfruit industries generally through:

- Greater knowledge within the industries about the impact and detection and management of SWD
- Mitigating biosecurity threats posed by a potential incursion and spread of SWD within Australia
- Maximising productivity through the effective management of any SWD incursion, including by integrating management plans into existing programs
- Minimising the impact of an incursion through application of effective surveillance and control options.

Methodology

A steering committee including representatives from project partners, and at least one industry and one state government representative, was established to oversee project direction and progress. The Steering Committee met through face to face and teleconference meetings to discuss specific issues associated with the delivery of the project.

In order to achieve the project objectives, activities were divided into four components as outlined below.

Component 1) A review of the potential entry pathways and impacts for Australia (including analysis of the preparedness and response capability in Australia)

This component utilised the Establishment, Spread, Impacts and Management (ESIM) framework for pest preparedness. This framework included pest population growth potential (establishment) and dispersal processes (spread), economic losses to crop value (impact), and surveillance, quarantine, and control strategies (management) and explore the cost-benefits of a range of response strategies. Component 1 has been addressed through a series of reports developed by **cesar.** They are:

- Report on modelling for spread and establishment of SWD (Appendix 1)
- Report on potential impacts of SWD (Appendix 2)
- Report on potential pathways for entry and spread (Appendix 3)
- Report on the surveillance and quarantine of SWD (Appendix 4)

Spread and establishment report summary

Briefly, the report on modelling for spread and establishment of SWD considers the ecoclimatic and economic drivers of SWD establishment and spread to improve forecasts of future incursions. Using a modular approach, climate-driven population dynamics are linked in space via dispersal processes to simulate spread at continental scales. Using biological parameters measured in laboratory studies, the resulting climate-based population growth model captured the global distribution and spread patterns of SWD providing confidence when projecting to ranges in Australia. Understanding the population dynamics of SWD overseas will be important for identifying high-risk import pathways but these same population models will also facilitate estimation of impacts to Australian horticultural industries, and optimal surveillance and extension strategies for early detection, as detailed below.

Potential impacts report summary

The report consisted of an international literature review on crop losses which was used with the establishment and spread model components to estimate the potential unmitigated economic impact of SWD to Australian horticulture. This was conducted for different jurisdictions and affected industries for a variety of incursion scenarios.

Pathway risk report summary

The report on the potential pathways for entry and spread built upon the previous risk analyses conducted by the Department of Agriculture, Water and the Environment. This work included a quantitative analysis on the risk of trade pathways that utilised the current global pest distribution, environmental suitability of import locations, and volumes of imported associated commodities.

Surveillance and quarantine report summary

This report explored the cost-benefit of different incursion response scenarios involving surveillance, quarantine, pest control, and industry awareness through their impact on establishment, spread, and impacts.

Using the ESIM framework, the likely pathways and impacts were estimated and assessed with specific reference to Australia's current preparedness and response capabilities. This has assisted in identifying shortcomings or opportunities in Australia's preparedness capabilities. These findings have also been used to identify more effective preparedness scenarios and surveillance protocols, which has directed the development of Component 3 (cross-commodity preparedness plan).

Component 2) A review of the management practices, incursion responses and impacts of SWD overseas (including a report on chemical control options} with a view to preparing appropriate management plans and permits should they be required

In order to gain an understanding of the management practices, incursion responses and impacts of SWD overseas desktop reviews were undertaken.

A review of invasion history, biology, trapping for surveillance and control of *Drosophila suzukii* was conducted by Plant and Food Research New Zealand [PFRNZ] and was used to support Components 1, 3 and 4 (see Appendix 5).

A review of control options for SWD was conducted by PHA which consolidated relevant information on SWD management practices through a search of the scientific and 'grey' literature, including independent trial reports, industry and government reports (Appendix 6). The chemical control literature review included efficacy of each chemical against SWD or related specie s (e.g. trial efficacy data, resistance potential, target life stage), current use of each chemical in Australia, effects of each chemical on beneficial species, and fit within IPM programs. The output of the review included the top products for SWD control in Australia ranked by 1) effectiveness of control; 2) toxicity to beneficials; 3) data needed to progress application; 4) resistance potential. Finally, the review provided a gap analysis to show where further research should be directed, such as residue trials for products not already used in Australia and efficacy trials for products new to SWD control.

Component 3). Develop a cross commodity contingency plan, including optimum surveillance protocols

The Preparedness Plan has largely been compiled using information generated through literature reviews, modeling report and stakeholder engagement activities as part of the project (Appendix 7). The plan includes information on SWD biology, host range, surveillance tools and methods, and control and management options. The document has been compiled as a preparedness plan rather than a contingency plan in recognition that eradication may be difficult as SWD is highly fecund, develops rapidly, and uses a large number of fruits from commercial to weed species as hosts. To have any potential to eradicate or slow the spread of SWD after detection, it must be found early, and host plant movement controls must be put in place immediately. No other country has eradicated SWD and it appears to spread very rapidly after initial detection. Therefore, the Preparedness Plan covers considerations for both eradication and management strategies – expected industry requirements should SWD become established in Australia. To support and provide a quick guide for the comprehensive preparedness plan a SWD preparedness basics document has been developed (Appendix 8).

Component 4) Develop and implement a communication and awareness program targeting potentially affected industries, including a workshop and an incursion response simulation exercise

Extension plan

A Communication, Engagement and Extension plan (CE&E Plan) was developed for the project. It supported project partners in achieving the end of project outcome ‘Improved SWD awareness and preparedness within the soft fruit industries to detect and respond to an incursion while building capacity for delimitation and containment to minimise the potential impact of this pest’. It also supported collection of monitoring data, as outlined in the project Monitoring and Evaluation plan.

Preparedness workshop

At the outset of the project **cesar** and Plant Health Australia collaborated to organise a SWD preparedness workshop, which was held on 29 October (figure 2). The first half of the workshop was dedicated to raising the level of knowledge in the room. A series of speakers (including international researcher visitors) delivered information on the following topics:

- SWD impacts and management in the United States
- SWD impacts and management in the United Kingdom
- SWD study tour findings from Europe
- Likely impacts of an incursion at the farm level – a grower perspective
- A comparison of QFly and SWD
- Supply chain impacts using Tomato potato psyllid as a case study

The afternoon included one breakout session where attendees were asked to assess supply chain weaknesses, and one longer scenario analysis session. Five scenarios were presented to the attendees, with questions to consider within the context of each scenario.

The workshop also involved use of Poll Everywhere, an online, cloud-based survey platform that allowed project partners to benchmark the level of awareness and knowledge about SWD at the beginning of the event and compare those results to data collected after the workshop.

Roadshow

From 30 October – 2 November a SWD awareness roadshow was undertaken (Table 1). Two international experts, Prof Rufus Isaacs (Michigan State University, US) and Bethan Shaw (NIAB-EMR, UK) accompanied project team members to four growing regions across four states.

A SWD seminar was held in each region), at which both international experts spoke in order to raise awareness about this fly and overseas management activities. Visits to major growing operations were also undertaken in each region, giving leading growers the opportunity to ask further questions about SWD.

Support in organising farm visits and raising awareness about these events was provided by the Costa Group, the Vic Strawberry Development Industry Association, Agriculture Victoria, AgriBusiness Yarra Valley, OzBerries, Tas Fruit Growers, Tasmanian Farmers & Graziers Association, RM Consulting Group, DPIPWE, TIA, NSW DPI, QLD Strawberries, Sunnyridge Farm, Hillwood Berry Farm, and Sensational Berries.

The seminars included additional biosecurity speakers as a ‘value add’ for attendees. These were Mandy Bowling (Biosecurity Officer, Tasmanian Farmers and Graziers Association), Bronwyn Koll (QFly Regional Coordinator, AgriBusiness Yarra Valley), and Cathy Mansfield (State QFly Coordinator, Agriculture Victoria). Two industry members based in Western Australia (from Summerfruit Australia and WA Strawberry Growers Association) also attended the grower seminar in the Yarra Valley with the intention of sharing that information with their constituency.

Changes due to COVID-19

Due to the COVID-19 situation the second preparedness workshop was cancelled. The team redirected efforts into the generation of outputs that would support the original objective of capacity building to still be met. There were three notable adjustments to extension activities during this period.

- Development and delivery of decision-aid tools for government, stemming from modelling results;
- Delivery of regional face to face updates were replaced with an end of project industry webinar;
- An ‘extension pack’ was developed that will supply extension officers with tools to continue awareness raising and education.

These adjustments were made in order to meet project objectives in the current COVID-19 environment, in response to stakeholder requests and assessment of outputs that will achieve high impact for industry, and to best ensure that industry education about the pest will continue after project conclusion.

Table 1. Roadshow itinerary and attendee results

Date	Region	Major Crops	Activities	Attendee #
30 October	Yarra Valley, Victoria	Grape, Rubus, strawberry, blueberries, cherries	Sunnyridge Strawberry Farm and Sensational Berries visits. 12.30pm seminar.	26
31 October	Tamar Valley, Tasmania	Grape, Blueberry, Rubus, Strawberry	Hillwood Berry Farm visit. 11.00am	35

			seminar	
1 November	Coffs Harbour, NSW	Blueberry, Rubus	Farm visits - Costa Farm Group and OzBerries visit. 5.30pm seminar.	16
2 November	Caboolture, QLD	Strawberry	5.00pm seminar.	11

Outputs

The level of awareness within the berry, summerfruit, cherry, and table grape industries about SWD and the level of preparedness for SWD was strengthened through this project by the delivery of the following outputs:

- Report on modelling for spread and establishment of SWD. This report modelled the ecoclimatic and anthropogenic drivers of SWD establishment and spread to improve forecasts of future incursions. Using biological parameters measured in laboratory studies, the resulting climate-based population growth model successfully captured the current global distribution of SWD providing confidence when projecting to novel ranges in Australia. A large portion of Australia's south-eastern range, as well as some restricted areas in western Australia were predicted to have climates that will support SWD populations. Simulated incursions into Australia, like those observed in Europe and the United States, were predicted to spread rapidly. More generally, simulated incursions across Australia highlight that eastern coastal regions, particularly those near cities would lead to fastest spread, with areas of 10,000 - 20,000 km^2 invaded after one year commonly predicted. The large variation in spread potential caused by incursion location will aid the design of delimiting surveys following a detection. Nonetheless, the general high spread potential suggests post-incursion eradication programs will be extremely difficult and expensive with border-security and quarantine programs likely to be most efficient.
- Report on potential impacts of SWD. This report included the first international literature review on crop losses. Mean reported crop losses varied most strongly with commodity type with impacts typically within 20-50% in the first 2 years following establishment and decreasing to under 10% after 6 years. Following this review, we use a spatially explicit simulation framework to estimate the potential economic impact of SWD to Australian horticulture under different incursion scenarios for different jurisdictions and industries. The estimated impacts of SWD in Australia were substantial, particularly for southern soft-fruit growing industries. Depending on the incursion location, predicted national accumulated impacts after three years varied from $16.6 – 61.3 million, reflecting rapid spread into its suitable range. Most impacts were predicted to occur in south-eastern Australia, particularly Queensland and Victoria, due to substantial strawberry, cherry and caneberry growing regions. Importantly, impacts did not necessarily scale with the size of the affected industry but also depended on the environmental suitability and isolation of each industry's production regions. These same factors also led to the incursion location associated with the highest impacts varying for each industry, which may lead to different biosecurity priorities for each industry.
- Report on modelling potential pathways for entry and spread. This report identified the most likely entry points to support early detection, we build on these past efforts with a quantitative analysis on the risk of trade pathways that utilises the current global pest distribution, environmental suitability of import locations, and volumes of imported associated commodities within and between years. Our analysis finds that some "low host-risk" commodities are imported in much higher volumes than preferred-hosts and may thus still pose import risks for SWD. The volume at which they are imported into different state-level jurisdictions, coupled with previous regional analysis on establishment and spread risks, suggests surveillance efforts may increase chances of early detection by prioritising monitoring in winter-spring periods around ports of entry for Victoria, New South Wales, and Queensland.
- Report on the surveillance and quarantine of SWD. This report extended the previously developed spatially explicit simulation framework of population growth and spread for SWD, to include surveillance, quarantine, and economic cost processes of SWD management. The cost-benefits of a range of surveillance, quarantine, control strategies were subsequently explored under different incursion scenarios. Despite assuming a high efficacy and low cost of quarantine and eradication, as well as optimistic early incursion detection at ports of entry, quarantine and eradication could not be demonstrated as economically rational for simulated incursions of SWD into Australia's major coastal cities over a 24-month time horizon. At shorter time horizons (i.e. 12 months), quarantine offered modest benefits in some incursion scenarios, with some support for the cost-effectiveness of eradication in Perth, due to its relative isolation from eastern soft-fruit production regions. The general low cost-effectiveness of the biosecurity responses explored here can be partly explained by SWD's large population growth potential, ability to travel via human-mediated pathways, and low sensitivity of current surveillance methods. In contrast to eradication and quarantine, increased pest awareness saw large returns on

investment due to enhanced early detection and reduced crop losses through appropriate pest management.

- A desktop review of Invasion history, biology, trapping for surveillance and control of SWD
- Control methods review. This desktop study provided an overview of chemical and other control measures. Based on comparison of overseas and Australian use pattern, the chemical control review recommended the following:
    - Application for an APVMA emergency permit for Maldison on berries (including Strawberries, Rubus berries, Ribes berries, Blueberries), stone fruit (including apricots, cherries, nectarines, peaches and plums) and grapes.
    - Application for an APVMA emergency permit for Bifenthrin on Rubus berries, gooseberries and Blueberries.
    - Application for an APVMA emergency permit for Clothianidin on peaches
    - Further research should be undertaken to determine suitable control options for SWD on citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), figs, kiwi, pome fruit (apples and pears), pomegranate and tropical/sub-tropical species (e.g. guava and feijoa), as no pesticide options were identified that are used in Australia on these crops at the same rate as used overseas for SWD control..
- SWD preparedness plan. This document provides background information on SWD to assist in determining the requirements for the initial response to a detection and management of this species in Australia. This outlined the impacts, the mechanisms for SWD to spread, and how potentially affected industries within Australia can best prepare for an incursion. If international experience with SWD is indicative of the risks posed to Australia's horticultural industry, considerable challenges lay ahead to minimise incursions, establishment, and spread, and ensure producers possess the knowledge that will enable them to quickly and smoothly transition to management. Simultaneously, Australia is in the fortunate position to be able to utilise the rapidly accumulating scientific knowledge that is rapidly being accumulated from overseas experiences managing this pest. If Australia utilises overseas experiences, through well-designed quarantine, diagnostics, surveillance and management strategies, the impacts of SWD can certainly be mitigated to a large degree. It was noted however that despite a growing volume of literature and knowledge on SWD, knowledge gaps still exist.
- Extension and communication. The project ran an initial workshop which was attended by 34 industry and government attendees from around Australia. Following this workshop, a roadshow was undertaken, with more than 120 growers and supply chain personnel of potentially affected industries directly learning about SWD from two our international guest speakers. These activities resulted in an energetic start to raising awareness and knowledge about SWD. Most attendees expressed an interest in staying involved as the project progressed and were placed on the SWD communication database, which formed the basis of a Community of Interest.
- A report for workshop 1 and accompanying gap analysiswas another output from the project that may be referred to in future to gain an appreciation of where stakeholders perceive needs to be in order to raise industry awareness and preparedness. The gaps identified in workshop 1 were compared to project outputs to establish how the project been able to fill these gaps, this is presented in Table 3.
- SWD extension pack. This output includes a wide range of communication and extension material produced within the project and includes:
    - PestBites identification episode
    - PestCase episodes
    - Article compendium
    - Video tutorials (In development)
    - Webinar recordings (2019 and 2020 webinar)
    - 'Get to know SWD' powerpoint presentation
    - SWD preparedness basics 'brochure'

- Lifecycle infographics

Not all material developed and included in this pack has been included as an Appendix due to the size of the files, the extension pack and its content is available at available at bit.ly/SWDExtensionPack

Industry articles, fact sheets, and web information developed during the project are described in Table 2.

Table 2. Extension activities

Item	Method of distribution	Publication date	Estimated reach
	2018		
Project flyer, including information on the pest, outlining the risk, and summarising the purpose and key outputs from the project. View flyer	Hard copies distributed at workshop, during grower visits, and at each roadshow seminar. E-Copies distributed to SWD communication database following roadshow. E-Copy uploaded to **cesar** website.	20 October	135 recipients
Short article in Horticulture NZ newsletter (contribution provided by the project).	Weekly Hort NZ e-newsletter.	Week of 1 November	1000 recipients (NZ)
Article developed for Cherry Australia in collaboration with CoreText.	Cherry Magazine	December edition	550 recipients
Article developed by the project team and published by RM Consulting Group.	The Punnet e-News View	21 November	315 recipients
One project article publicising the roadshow.	**cesar** News (publicised through Twitter @cesaraustralia) View	22 October	1300 followers
One article outlining the risk posed by SWD.	**cesar** News (publicised through Twitter @cesaraustralia) View	19 October	1300 followers
Regional news publication raising awareness about SWD (figure 1).	Mountain Views Mail Ferntree Gully & Belgrave Mail Mount Evelyn Mail Ranges Trader Mail Upper Yarra Mail	22 November	Circulation of 30,000
Plant Health Australia communique	Posted on website and published in Tendrils e-Newsletter View	9 November	---
Seminar slides from SWD roadshow	Uploaded to the Strawberry Innovation website and supplied to SWD extension database. These slides, and seminar footage, were also supplied to Biosecurity Tasmania on request, and to the University of Tasmania for training purposes.	December	Unknown
	2019		
Project webpage	Project details are now hosted on the **cesar** website. Project information, such as updates, are uploaded to this webpage. View	5 January 2019	
Project update, spring 2018	Initially published in Cherry Magazine, then added to the Prevent Fruit Fly website.	20 Feb 2019	Approx.. readership of 550 for Cherry Magazine
Project update, summer 2019 View update	Distributed via: Blueberry grower newsletter, Very Berry E-Newsletter The Punnett e-News Cherry Magazine Australian Berry Growers Journal	Article developed on 11 February. Publication date of the article since 11 February has depended on the distribution method.	>1300 recipients

	Direct email from WA Strawberry IDO to industry network Direct Mailchimp to SWD extension database Uploaded to the project page on the **cesar** website		
Preparedness webinar (see webinar agenda below)	Hosted by Strawberry Innovation Program, recorded and hosted on YouTube, as well as the Strawberry Innovation website and the **cesar** website. The recording was also circulated over social media by **cesar** and the Strawberry Innovation Program.	11 April	18 viewers on 11 April. At the time of writing the webinar had 26 views on YouTube.
Project Update Winter 2019 (2rd update from project) Title: Spotted wing drosophila: where will this world citizen make its next travel destination? Link	Audience: Growers, agronomists, industry development staff Distribution: • **cesar** e-news • Hosting on online project page (**cesar** website) • Direct mailout to SWD distribution list • Australian Tree Crop Magazine • Very Berry e-News	August 2019	>1000
SWD identification video (Pest Bites episode) Link	Audience: Growers, agronomists, industry development staff, biosecurity staff Distribution: • Twitter campaign through @cesaraustralia, tagging relevant organisations (Figure 1). • Direct release to SWD distribution list. • Video file provided on request to industry organisations.	Launched August 2019 (promotion ongoing)	164 views since release.
Plant Biosecurity Research Initiative conference talk Title: Preparedness for spotted wing drosophila: An integrated approach	Audience: Researchers, government biosecurity staff	15 August 2019	Approx. 200 attendees
Victorian Farmers Federation Biosecurity Forum talk (Mornington Peninsula)	Audience: Growers, industry development staff, biosecurity staff	24 June 2019	Approx. 40 attendees
Landcare Agricultural Facilitator meeting (Victoria) talk	Audience: Landcare Agricultural Facilitators	5 September 2019	6 Landcare Facilitators
University of Melbourne 'Dookie Day' Biosecurity Stall. Stall included SWD preserved specimens and a powerpoint display showing SWD features of identification and impact.	Audience: Agricultural students, Melbourne and Goulburn Valley residents.	22 September 2019	>200 engagements
Bundaberg Fruit and Vegetable Grower conference talk	Audience: Growers, agronomists, industry development staff	22 October 2019	Approx. 60 attendees
SWD Pest Case videos, which features interviews with growers in the UK.	Audience: Growers, agronomists, industry development staff		
Conference talk Title: Mechanistic forecasting of exotic pest establishment and spread - an integrated approach for industry preparedness	MODSIM Conference Modelling scientists	3 December 2019	50-100
Project article	Audience: Growers, agronomists, industry	1 December 2019	>1000

SWD: Tips to stay ahead See appendix 1.	development staff Australian Tree Crop Magazine		
Project article Title: SWD: Where will this world citizen make its next travel destination? Link	Audience: Growers, agronomists, industry development staff Australian Berry Journal	10 December 2019	>1000
Project article SWD: The overseas experience & tips to stay ahead Link	Audience: Growers, agronomists, industry development staff, researchers, government • **cesar** e-News • Audience: Growers, agronomists, industry development staff • Australian Berry Journal	9 December 2019	<100
	2020		
Modelling consultation meetings (x4)	Government biosecurity policy and surveillance personnel Fact to face delivery or over video conference.	Jan-March	9
Seminar	CEBRA Scientists	5 March 2020	<50
Project article Title: Exotic pest profile: spotted wing drosophila Link	Farm Biosecurity eNews	14 February 2020	National reach
Tasmanian Fruit Growers Association / VegNet Tasmania webinar Title: Get to know SWD Link	Audience: Growers, agronomists, industry development staff Webinar was held to a live audience and uploaded the RMCG YouTube and the SoilWealth platform.	27 March 2020	10 attendees.
Project article Title: Management considerations for SWD	Audience: Growers, agronomists, industry development staff Supplied to Australian Tree Crop Magazine and Australian Berry Journal for publication.		
SWD PestCase: Part 1, which features an overview of SWD and interviews with Plant Health Australia and **cesar** researchers. *Final version has been sent to project partners for sign off.*	Audience: Growers, agronomists, industry development staff	May 2020	79 views
SWD PestCase: Part 2, which features interviews with growers in the UK. (This is an output of MT18010 but it will be distributed through channels developed throughout MT17005) *Final version has been sent to NIAB-EMR and interviewees for sign off.*	Audience: Growers, agronomists, industry development staff	May 2020	35 views
End of project webinar	Audience: Growers, agronomists, industry development staff in Australia and New Zealand.	30 April 2020	98

Table 3: Identified gaps from workshop 1 and associated project outputs which have assisted in filling gaps identified.

	Identified gaps **(What do we not yet know, do not yet have, or cannot yet do effectively?)**	**Project outputs** **(How has the project been able to fill these gaps)**
Pathway management & first report	• Grower awareness and education (eg. small growers may not have a good understanding of SWD as a threat)	• Awareness roadshow with international experts to four growing regions across four states. • The PestCase and PestBites videos represent outputs that present awareness material. Articles for industry publications • Project flyer, including information on the pest, outlining the risk, and summarising the purpose and key outputs from the project. • Project updates
	• Public awareness (eg. about checking fruit at home)	• This remains a gap
	• Trap network for early detection	• Cost benefit analysis conducted indicated that eradication required high trapping densities to meaningfully reduce rates of spread
	• Understanding of non-commercial hosts	• A detailed list of potential host has been compiled and included in the preparedness plan.
	• Educating public and growers (extension)	• Extension pack consisting of all project extension material developed. • Landcare Agricultural Facilitator meeting (Victoria) talk
	• Review requirements on exporting countries	• This remains a gap
Managing a first detection	• Method for measuring abundance and linkages to production impact	• Impact assessment was looked at
	• International relationships (sending researchers/growers overseas collect advice and find answers	• This remains a gap
	• Understanding appropriate distance for exclusion zones	• This remains a gap however through the foundational information generated in the project this can be derived.
	• Trapping protocols for SWD	• A list of considerations for trapping SWD has been presented in the preparedness plan. No single tapping protocol has been proposed due to complexities surrounding trapping of SWD
	• Grid sensitivity not known	• The report on surveillance, quarantine, and eradication potential in Australia identifies the area of trapping required to delimit spread

	• Information on expected density and population numbers	• Predictions of SWD density and population numbers is presented as mean growth rate 1/d in the report on spread and establishment.
	• Sex pheromones and specific SWD lures that are more attractive than commercial hosts	• Information on trap types is presented in thh SWD preparedness plan.
	• Understanding of ability to naturally spread / biology and behaviour	• The spread and establishment model can predict the spread and establishment ion Australian considering mitigated and unmitigated spread.
	• Having a live SWD culture in the country for research purposes	• This remains a gap
	• Clarity for growers about what to expect in regard to exclusion zone set up and restrictions	• This remains a gap
Managing market access	• Pre-agreed interstate market access movement conditions (ICAs and movement controls)	• This remains a gap
	• Formal and agreed destruction process for waste	• Information is presented in the Preparedness plan, this information can for the basis of a formal agreed process.
	• Commodity data to support post-harvest treatments, such as irradiation and MeBr (eg. For FSANZ approvals)	• Commodity data has been obtained however there are several consideration that are need when using this data. No formal assessment on post harvest treatments have been considered.
	• Standard operating procedure (SOP) for secure movement of product to treatment / storage facilities	• This remains a gap however information presented in the preparedness plan can assist in the development on SOPs
	• Biosecurity education (particularly for weekend warriors, U-pick, small farms etc..)	• Landcare Agricultural Facilitator meeting (Victoria) talk
	• Strategies for managing public involvement	• This remains a gap
	• Strategies for managing public protecting market access	• This remains a gap
	• Understanding of what countries have SWD and how they are managing market access requirements	• A list of global distribution is presented in the preparedness plan and project literature reviews. No comment on how they are managing market access has been made.
Management	• Management plan that can be achievably adopted (assessed for cost effectiveness etc.)	• Preparedness plan provides information on the various management measure available for SWD

	• IPM planning	• See project MT
	• Efficacy data to support product registration / minor use permit approval	• Literature review of chemical control options in Australia.
	• Plan for educating producers about management measures	• No post project plans for continues extension has been made, this remains a gap.
Extension and adoption	• Method of getting information out to communities (e.g. through councils, a lot of pressure will come from peri-urban areas)	• This remains a gap
	• Simple messaging for communities and industry	• Preparedness basics brochure • The PestCase and PestBites videos represent outputs that present awareness material.
	• Method of coordinating messaging across industry	• Extension pack This output includes a wide range of communication and extension material produced within the project
	• Identify trusted advisors who would hand out information that is formally endorsed	• Extension pack hand over webinar

Outcomes

Through activities undertaken this project the project has resulted in the following outcomes:

1. **Increased awareness within the berry, strawberry, cherry, summerfruit and tablegrape industries of the threat posed by SWD and how to identify the pest.**

Awareness activities were undertaken throughout the project in line with the plan, enabling the project to become an information source about SWD. Activities such as social media posts, industry articles and engagement with the SWD community of interest allowed the project to remain engaged with key audiences at regular intervals.

The social media campaign and ongoing engagement with a spotted wing drosophila Community of Interest (CoI) lended consistency to the awareness and education campaign. For instance, the CoI, which had its origins in the researcher roadshow undertaken in the early stages of the project, was regularly emailed with updates on project progress and new outputs, which enabled this community to grow. By the conclusion of this project the COI was a highly engaged group, that may act as preparedness champions going forward.

This project has acted as a central hub for information on spotted wing drosophila. For example, information and spotted wing drosophila graphics have been supplied to the Urban Plant Health Network for use in educating the general public about spotted wing drosophila. In addition, a social media campaign and ongoing engagement with a spotted wing drosophila Community of Interest (CoI) have provided consistency to the awareness and education campaign.

2. **An understanding of the tools available for monitoring SWD and the efficacy of those tools**

This was achieved through the literature review compiled by PFRNZ and the subsequent compilation of the preparedness plan. In Australia there are several surveillance tools available for use however the most important consideration for surveillance activities is that trap catches do not necessarily reflect population density as SWD is usually preferentially attracted to fruit present in the vicinity rather traps, despite the increasing development and deployment of lures. Experience from overseas has shown that while traps are therefore a useful for monitoring SWD levels in management programs, they are not thought to be useful for early detection of new populations, as any level of trap capture is likely to be indicative of a high population of SWD in the surrounding area.

3. **An understanding of the chemical and non-chemical control options for SWD as investigated overseas and how these would be applicable to Australian conditions. Recommendations proposed provide management options to growers in the event of an incursion**.

Through reviews of chemical and non-chemical control options and discussions and input from growers with an overseas experience in managing SWD, the project has been able to present recommendations for the management of SWD. The Pest Bites episode 2 provides a grower's experience managing SWD which may assist growers in the event of an incursion. Other outputs including a list of recommended chemical control options for an emergency permit.

4. **An approach for prioritised surveillance that considers the potential pathways through which SWD could arrive and spread in Australia**

This outcome is presented in the import report and the Preparedness plan, a framework for key points of consideration for development of early detection and delimiting surveys for SWD is presented that take into account climatic suitability, land use, host availability, season, points of entry, origin of fruit imports and fruit disposal.

5. **A framework to simulate different incursion scenarios, industry responses, and their associated impacts**

Though work conducted by Cesar a framework for pest preparedness has been developed that considers Establishment, Spread, Impacts and Management (ESIM). This framework included pest population growth potential (establishment) and dispersal processes (spread), economic losses to crop value (impact), and surveillance, quarantine, and control strategies (management) and explore the cost-benefits of a range of response strategies. The establishment, spread, impact and management model developed for SWD will remain a useful resource to explore further scenarios of interest in future, such as in the event of an incursion or for further preparedness studies.

6. Identification of knowledge gaps that will help to prioritise future investment.

Despite a growing volume of literature and knowledge on SWD there are knowledge gaps in preparedness, and these are outlined with the preparedness plan. This will also be discussed in the recommendations section of this report.

7. Improved preparedness for any SWD incursion with available tools for control, containment and eradication of SWD in commercial production and trade identified and critiqued.

This has been achieved though the project reports and the preparedness plan, this preparedness plan provides background information on SWD to assist in determining the requirements for the initial response to a detection and management of this species in Australia. Further to these meetings with chief plant heath officers of state jurisdictions ensured awareness of project outputs but also garnered feedback to improve presentation of project outputs to maximum utility in response planning. Through these discussions several outputs emerged that will assist preparedness including:

- Estimated industry impacts (by crop) through time for each jurisdiction under various incursion scenarios
- Interactive web page with preloaded spread simulations for any incursion location with production industry location overlaid
- Eradication potential and cost-effectiveness of management responses for different incursion scenarios
- Trapping density guidelines

Monitoring and evaluation

An internal evaluation report (see appendix 9) was undertaken under the Monitoring & Evaluation Framework prepared at the outset of MT17005. Results indicate that the project met, and in many cases exceeded, intended outcomes. Five key evaluation questions were identified in the plan. Table 4 provides a list of key evaluation questions and measures of success.

Project evaluation has been continuous thought the project. Awareness activities have been a particular highlight with several opportunities to propagate knowledge of SWD within Australian horticultural industries. Given the preemptive approach to preparedness being taken within this project it has continued to receive positive feedback from horticultural representatives. The steering committee has provided ongoing feedback on project deliverables. There have been some structured evaluation tools used within the project to understand knowledge change throughout the project. A major evaluation activity was conducted during workshop 1, this involved the use of Poll Everywhere, an online, cloud-based survey platform that allowed project partners to benchmark the level of awareness and knowledge about SWD at the beginning of the event and compare those results to data collected after the workshop.

Project evaluation is still ongoing with a final survey to be sent to the COI in early July 2020. The information obtained from this survey will be used in combination with the results from polling in workshop 1 to provide an insight into the change in knowledge as a result of project activities.

Further, these project activities have been an excellent example of achieving cost efficiencies and sharing skills and information through collaboration with New Zealand organisations.

Table 4 Project key evaluation questions

Key evaluation questions	Project-specific questions	Measures of success
1. To what extent has the project achieved its expected outcomes?	To what extent has the knowledge of SWD as a pest and how to identify it increased within the potentially affected horticultural industries?	Metrics on knowledge change as a direct result of project activities is included in the internal evaluation report. In each case where knowledge change was captured the project team can show evidence of improved knowledge in relation to SWD.
	To what extent has a prioritised surveillance plan for SWD increased confidence in early detection?	Based on personal communications with a surveillance officer in one state government the project provided enough robust surveillance planning research to provide this officer with confidence to integrate SWD into 2021 state surveillance activities.
	What increase has there been in the confidence of the potentially affected horticultural industries to implement control measures for SWD should they be necessary?	While this project did not have a focus on SWD 'control', rather awareness, surveillance, economic and pathway risk assessment, the SWD Extension Pack handover sessions are an example of a project activity where industry development officers in particular were equipped with the outreach materials necessary to aid preparedness and response. Further, the prior- and post- workshop poll in 2018 indicated that there was a notable increase in confidence due to the workshop when attendees were posed the question: *Based on your current knowledge, how confident are you personally of managing SWD or providing management advice? (Refer to the Preparedness Workshop Report)*
	Are chemical and non-chemical control options for SWD available in Australia, or has a plan been developed to making sure these options will be available in the future?	The preparedness plan makes a few recommendation for emergency permits however It is also recommended that further research is undertaken to determine suitable control options for SWD on citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), figs, kiwifruit, pome fruit (apples and pears), pomegranate and tropical/sub-tropical species (e.g. guava and feijoa). As no pesticide options were identified that are used in Australia on these crops at the same rate as they are used overseas for SWD control, making this a potential gap in Australia's preparedness for SWD. However, while the project has potentially supported

		future efforts to achieve this, making chemicals available for use was not an aim of the project.
	Overall – do the potentially affected horticultural industries consider that they are now better prepared for any incursion of SWD?	Metrics collected throughout the project and collated in internal evaluation report indicate that within the sub-population of industry personnel who directly engaged with the project there has been and increase in knowledge and awareness for SWD. By enabling industry development personnel to continue outreach work this improvement in knowledge and awareness is likely to continue. Feedback from government personel throughout the project has indicated that they feel more equipped to make decisions about SWD, both prior to and after an incursion. It is difficult to make an assessment on the wider industry who may have been engaged on social media and through project articles. One major highlight of the project has been the SWD Steering Committee, who are a group of dedicated individuals intent on raising preparedness for SWD. This group now have access to the latest information and predictions about SWD and it is likely that individuals in this group will continue to share their knowledge.
2. How relevant was the project to the needs of intended beneficiaries?	To what extent has the project met the needs of potentially affected horticultural industries in preparing for the threat posed by SWD?	Data gathered during the roadshow indicates that information presented during the roadshow was extremely relevant to the audience and would be used / transferred. Feedback received over the course of the project is also indicative of meeting this key evaluation question. The number of people engaged in project activities tended to be high and increased as the project progressed and became familiar to people. The number of people that attended the SWD handover sessions (60 across two sessions) and subsequent accessing of the Extension Pack (93 at the time of writing) indicates that the project was meeting the needs of potentially affected industries. Reasons for sitting in on the handover sessions included: • 'early detection and reporting' • 'managing delivery of biosecurity surveillance programs' • 'I consult' • 'raise awareness for a serious biosecurity pest' • 'help protect industries' • 'industry viability / control' • 'info for growers / industry' The theme of 'raising awareness' was common among participants. It was also noted during these sessions that the virtual breakout rooms enabled connections to be made and ideas to be explored. One outcome of these sessions has been connections made between a small group of government and industry individuals who are interested in developing a surveillance program. It is also important to note that government biosecurity personel were regularly engaged throughout the project in order to meet their information needs, which will in turn increase Australian-New Zealand regional capability to mangage risks relating to SWD.
3. How well have intended beneficiaries been engaged in the project?	Have the soft fruit industries, the growers they represent, and government been involved in SWD communication and	The breadth of extension activities and strong engagement from industry indicates that this criteria was achieved. Refer to the extension outputs table of the final report and the audience segmentation section of this report for evidence of

	awareness activities?	this achievement. The collaboration between Australian and New Zealand has been a strength of the project as an incursion of SWD in either country is likely to have negative flow on effects to the nieghboring country in terms of heightened risk and trade impacts. Pan regional preparedness will be important for limiting the risks posed by SWD.
4. To what extent were engagement processes appropriate to the target audience/s of the project?	How effective was the projects' engagement with the potentially affected horticultural industries, the growers they represent and governments?	Metrics presented in this report and the extension section of the final report indicate that project engagement with a core group of stakeholders was highly effective. This core group (the COI) are industry and government leaders and include the major decision-makers, knowledge brokers, and industry capacity builders when it comes to exotic pest preparedness. As an example, EE Muirs and Sons, a large scale provider of entomology advice for affected industries, is interested in using the Extension Pack for internal capacity building (EE Muirs and Sons agronomist, per comms).
	Was the information presented in a way that was useful to the potentially affected horticultural industries?	The extension activities included a wide range of format types, including video, webinars, face to face talks, and articles, in order to meet the education preferences of a diversity of industry stakeholders. The PestCase and PestBites videos in particular represent outputs that present awareness material in a unique format. Growth of YouTube viewership and continued support by industry magazines indicates that these formats were usefull. The popularity of the Extension Pack also indicates this.
5. What efforts did the project make to improve efficiency?	What has the project achieved to make surveillance for and any response to an incursion of SWD more efficient and effective?	Knowledge on the tools available the effectiveness of these tools is presented in the preparedness plan. Management and surveillance options have been included in extension activities. The Extension Pack will be a usefull resource for aiding consistent communication to industry should SWD be found in Australia.
	To what extent has the project identified scientific, regulatory, or knowledge gaps that require future prioritisation and investment?	Gaps in preparedness are provided within the preparedness plan. In addition, a gaps breakout session undertaken during the Preparedness Workshop, and a gaps poll sent to the COI resulted in a prioritised list of gaps that are captured in the Preaparedness Workshop report.

Recommendations

The work completed by this project has helped consolidate information and raise awareness on SWD. However, it is important that the significant momentum generated by this project is maintained and that a commitment to ongoing improvement in biosecurity preparedness is achieved through an investment in continued preparedness activities for SWD and other high priority pests.

Awareness amongst, growers and government has been raised through this project. Despite these efforts there is a need to increase awareness in the urban and peri urban environments and the industry supply chains as well as continue with grower awareness and education. In the UK experience, proactively raising the level of knowledge about SWD within affected industries was described as the key in ensuring that growers could quickly implement management plans. Continuation of awareness can be facilitated by establishing a local working group that can be 'activated' to act as an information source and trusted communicator during an incursion.

The steering committee has identified a need to continue their role, however recommend the focus of the group transitions to a an advisory committee providing guidance on future activities and practical steps in SWD preparedness.

The collaborative nature of the project illustrated the benefit of ongoing collective investment for strengthening R&D cooperation between Australia and New Zealand. It is recommended that these arrangements be utilised in future preparedness activities.

A list of actions have been included in the preparedness plan, a summary of Recommended preparedness activities are presented in Table 4 below

Table 5: Recommended preparedness activities

Action Areas	Priority	activity length[1]
Prevention		
Maintain appropriate regulation at the border. Specifically: - Industry should engage with the federal government to ensure maintenance of appropriate conditions for limiting risk of long-range SWD transmission into Australia. - Governments should make use of pathway risk analysis conducted as a part of this project to improve risk mitigation where necessary.	High	Long
Ongoing collection and assessment of interception data by the federal government to identify any changes to the risk status of pathways	High	Long
Diagnostics		
Finalise the National Diagnostic Protocol for SWD	High	Short
Continue to develop high through-put diagnostic tools for rapid diagnostics and improvements to surge capacity[2]	Medium	Medium
Surveillance		
Provide key high-value host crop production regions with training and resources necessary to establish a program of surveillance for adults and larvae using traps and the flotation test	High	Medium
Establish a surveillance program in high risk sites such as fresh produce markets and areas that receive host products from overseas	High	Medium
Initiate regular reviews of new information on trapping and surveillance techniques used overseas to improve outcomes for early detection	Medium	Long

[1] Short term – up to 1-2 years; Medium term – 3-5 years; Long term 5+ years
[2] Noting that research is currently being undertaken in this area within the RRD4P project to improve diagnostics for plant pests in Australia

Develop and/or utilise tools and systems to capture, store and analyse surveillance, spatial and diagnostic data	Medium	Medium
Preparedness for management and control		
Review new information on lure and kill technologies as they it is developed overseas, including assessment of any barriers for registration for ongoing use of products in Australia	High	Short
Investigation into post-harvest treatments that may be applied to SWD-infested produce in Australia, with a view to understanding where treatments may align with Qfly arrangements, and where further data is necessary to support implementation of SWD arrangements.	High	Short
Application and ongoing review and maintenance of emergency permits for SWD. Specific requirements are: - An APVMA permit for Maldison on berries (including strawberries, rubus berries, ribes berries, blueberries), stone fruit (including apricots, cherries, nectarines, peaches and plums) and grapes. - An APVMA permit for bifenthrin on rubus berries, gooseberries and blueberries. - An APVMA permit for clothianidin on peaches.	High	Short
Where needed, undertake collation of appropriate efficacy data required for ongoing permits to support management, and provision of advice to permit holders in regard to necessary field trials for filling data gaps.	High	Medium
Undertake cost analysis for supply chain component to estimate additional expenses for management of SWD.	High	Short
Detailed investigation into alignment of Qfly management and SWD management in order to highlight where areas of similarity may support time and cost-savings.	High	Short
Undertake a short review of current export country partner requirements in relation to SWD, identify potential export risks and design of strategies for protection of market access, including development of standard operating procedures for movement of produce from affected regions for Australian growers.	High	Short
Ongoing research on control methods used overseas to continue to collect and refine management advice within an Australian context to mitigate the impacts of SWD in fruit production systems in the case of an incursion and establishment.	Medium	Long
Assess the effectiveness of hot and cold composting of fruit and waste for destruction of SWD, and waste burial tactics.	Medium	Medium
Investigate potential for deployment of Sterile Insect Technology in Australia, including compiling information on mass rearing techniques and undertaking a benefit:cost assessment for its use.	Medium	Short
Engagement and awareness		

Initiate an education campaign that promotes incorporation of cultural control management techniques, particularly related to hygiene and waste disposal, into best practice for fruit production for soft and thin-skinned fruits such as raspberry, blackberry, strawberry, blueberry cherry and summerfruit crops	High	Long
Maintain SWD engagement and awareness activities in raspberry, blackberry, strawberry, blueberry, cherry, tablegrape, and summerfruit industries. Expand awareness activities to pome and winegrape industries through strategic cross-industry and trans-Tasman collaborations.	High	Long
Investigate methods of strengthening communications between federal government biosecurity personnel and industry in order to support focussed awareness activities during high risk years	High	Long
Development of a communication plan for soft-fruit industries to support incursion response and business continuity in the event of an incursion, including: - Design of a public relations strategy to limit consumer backlash and support ongoing soft-fruit sales; - Clear messaging for farm and other supply chain businesses; - Methods of sharing information with affected and unaffected communities; - Identification of trusted advisors who could aid in communications.	High	Short
Design and implement an awareness campaign directed at urban and peri-urban communities surrounding high traffic ports-of-entry.	Medium	Short

[1] Short term – up to 1-2 years; Medium term – 3-5 years; Long term 5+ years

[1] Noting that research is currently being undertaken in this area within the RRD4P project to improve diagnostics for plant pests in Australia

Intellectual property, commercialisation and confidentiality

report presented in appendices Appendix 3 is confidential

No other IP, outputs, or commercialisation issues to report.

Appendices

- Appendix 1: Report on modelling for spread and establishment of SWD
- Appendix 2: Report on potential impacts of SWD
- Appendix 3. Report on potential pathways for entry and spread (CONFIDENTIAL)
- Appendix 4. Report on the surveillance and quarantine of SWD
- Appendix 5. literature review on Invasion history, biology, trapping for surveillance and control of *Drosophila suzukii* PFRNZ
- Appendix 6. Review on control methods for SWD
- Appendix 7. SWD preparedness Plan
- Appendix 8. SWD preparedness basics
- Appendix 9. Internal evaluation report

The spread and establishment potential of spotted-wing drosophila in Australia

Confidential Report

June 26, 2020

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Executive Summary

In the last decade spotted winged drosophila (*Drosophila suzukii*) has rapidly emerged as an agricultural pest of international importance. Accumulated international knowledge will be vital in developing effective preparedness strategies for this pest for countries that have identified *D. suzukii* as a major biosecurity threat, such as Australia.

Here, we modelled the ecoclimatic and anthropogenic drivers of *D. suzukii* establishment and spread to improve forecasts of future incursions. Using a modular approach, climate-driven population dynamics are linked in space via dispersal processes to simulate spread at continental scales. Using biological parameters measured in laboratory studies, the resulting climate-based population growth model successfully captured the current global distribution of *D. suzukii* providing confidence when projecting to novel ranges in Australia. The spread model was then parameterized and validated on international spread data where it was found to predict 83% of the state-level presence-absences though time in the United States and, without further model fitting, 73% of the variation in the Europe incursion. The largest contribution to predictability was the human-assisted spread module, which reduced predictability by almost 25% when omitted. This highlights the large role of human assisted spread in this modern biological invasion.

A large portion of Australia's south-eastern range, as well as some restricted areas in western Australia were predicted to have climates that will support *D. suzukii* populations. Simulated incursions into Australia, like those observed in Europe and the United States, were predicted to spread rapidly. For example, an incursion into the eastern Australian city of Brisbane resulted in a mean predicted occupied area of 15,763 km^2 (for incursions commencing in January) and 21,254 km^2 (for incursions commencing in July) after only one year from arrival. More generally, simulated incursions across Australia highlight that eastern coastal regions, particularly those near cities would lead to fastest spread, with areas of 10,000 - 20,000 km^2 invaded after one year commonly predicted. The large variation in spread potential caused by incursion location will aid the design of delimiting surveys following a detection. Nonetheless, the general high spread potential suggests post-incursion eradication programs will be extremely difficult and expensive with border-security and quarantine programs likely to be most efficient.

Introduction

In an increasingly connected world, tremendous pressure from global trade and human movement has resulted in the inundation of Earth's ecosystems with invasive alien species (Westphal et al. 2008; Hulme 2009). Recent invasions have resulted in significant negative impacts on agricultural productivity (Pimentel et al. 2001) and major disruption to core components of ecosystem function such as carbon cycling (Fei et al. 2019).

Within a decade, *D. suzukii* has become a globally significant pest of a range of soft, thin-skinned fruits including blueberries, caneberries (e.g. blackberries, raspberries, loganberries and youngberries), cherries, strawberries, summerfruit, and grapes (Asplen et al. 2015). In contrast to most Drosophila species, *D. suzukii* is capable of laying eggs (ovipositing) into ripe and ripening, undamaged fruit (Atallah et al. 2014). While *D. suzukii* was first described in Japan in 1931 and is present throughout several Asian countries, its potential importance as a production pest was only fully realised after incursions into the United States and Europe in 2008 with observed crop losses of 20-40% in caneberries, strawberries and cherries (Bolda et al. 2010; Cini et al. 2012). Despite its global significance, dispersal patterns of *D. suzukii* after its arrival to new continents have remained unexplored. This reduces our ability to predict how it will behave in other exotic ranges and thus limits capacity to develop robust preparedness strategies.

Drosophila suzukii is not known to be present in Australia, but fruit industries, valued at $4.8 billion, remain highly vulnerable to an incursion (HIA 2019). Independent studies modelling the potential global distribution of *D. suzukii* have concluded that there are substantial regions of Australia with high climatic suitability (Dos Santos et al. 2017; Ørsted and Ørsted 2019). Despite natural isolation and a rigorous approach to biosecurity, Australia's Department of Agriculture has identified the lack of an established control program could result in significant impacts on horticultural industries pest (Department of Agriculture Fisheries and Forestry Biosecurity 2013). Even after the transition to management, *D. suzukii* has caused major disruption to existing integrated pest management programs in the United States through a reliance on broad spectrum pesticides (Van Steenwyk and Bolda 2014), which has led to the resurgence of previously managed pests. To improve industry preparedness and response to a *D. suzukii* incursion, understanding establishment and spread processes is required before designing monitoring and management strategies for risk mitigation.

Here, we integrate modern mechanistic insights around dispersal processes and test their contribution to explaining the recent global invasion patterns of *D. suzukii* in order to produce robust predictions for Australia. Specifically, we aimed to quantify the predictability of spread patterns of *D. suzukii* across the United States and Europe and estimate the impact on predictability when key dispersal processes are omitted. This will identify the key processes driving the spread and establishment of *D. suzukii* overseas so that it can be better managed in Australia should it establish.

Methods

Climate and population growth

Since the extension of reaction diffusion equations for growing populations (Skellam 1951) the influence of population growth on rates of dispersal has been widely appreciated. Population growth potential through time represents the boundary conditions constraining permanent establishment, rates of spread, and subsequent impacts. Understanding population growth is important as regional and seasonal variation in ecoclimatic conditions and suitability will cause populations to grow and shrink at different rates. This variability in population dynamics will in turn impact rates of spread and establishment. Thus, we firstly develop a population growth model for *D. suzukii* based on climatic constraints that drives local population dynamics.

The intrinsic rate of population growth r is the exponential growth rate of a stable population N through time t or $\frac{dN}{dt} = rN$. The temperature response of positive growth rate r_p is modelled using a formulation of Sharpe and DeMichele model (Schoolfield et al. 1981) and parameterised from empirical data and non-linear least squares regression (Figure 1). Negative growth rate is parameterised from studies of *D. suzukii* mortality under stress and is assumed to occur once an environmental variable s exceeds some threshold (e.g. critical thermal maximum), beyond which the mortality rate scales approximately linearly with the depth of the stressor (Enriquez and Colinet 2017). Stressor induced mortality can be incorporated through quantifying the threshold s_c beyond which stress associated mortality commences, and the mortality rate parameter m_s which reflects the per capita mortality per stress unit per time. The mortality rate for each stressor s can thus be incorporated as $\frac{dN}{dt} = (r_p - r_n)N$ where $r_n = \sum_s f(S, c_s)m_s$ and $f(S, c_s)$ is a function that provides the positive units by which s exceeds s_c. A carrying capacity (K) can be used to place an upper bound on population growth using the simple logistic formulation of $\frac{dN}{dt} = (1 - N/K)(r_p - r_n)N$.

Here we consider the thermal stressors (critical maxima and minima) as well as moisture stress. Temperature stressors are usually more studied than water-mediated stressors. *Drosophila suzukii* is herbivorous so, rather than soil moisture, we take proportion of soil at permanent wilting point to be more relevant, which considers the effects of soil type on water potential. Once these thresholds have been exceeded, the mortality rate m_s for each stressor s can be estimated from previous studies using the solution to the intrinsic growth differential equation when growth rate is non-positive, $p = e^{-m_s a_s t}$ where p is the surviving proportion and a_s is the accumulated stress units until time t. Table 1 provides estimates for threshold parameters for climatic stressors, which are validated against physiological and actual and prediction distribution data in Figures 1 and 2.

Table 1. Parameters for critical thresholds and mortality rates for key environmental stressors.

Parameter	Description	Value	Justification
$\boldsymbol{c_{T_{min}}}$	Critical minimum temperature, °C	-10	Stephens et al. 2015 and Figure 1
$\boldsymbol{m_{T_{min}}}$	Mortality rate per cold stress, °C/d	0.21	Stephens et al. 2015 and Figure 1
$\boldsymbol{c_{T_{max}}}$	Critical maximum temperature, °C	35	Enriquez and Colinet 2017 and Figure 1
$\boldsymbol{m_{T_{max}}}$	Mortality rate per heat stress, °C/d	0.365	Enriquez and Colinet 2017 and Figure 1
$\boldsymbol{c_{wilting}}$	Critical wilting fraction, -	0.50	There is little data on *D. suzukii* under moisture stress, and so 50% of plants wilting is arbitrarily assumed as the moisture stress threshold.
$\boldsymbol{m_{wilting}}$	Mortality rate per desiccation stress, 1/d	4.6	Tochen et al (2015) demonstrated that *D. suzukii* adults at 20.2 C and 20-33% relative humidity survived for 1.5-2.5 days, which we use to parameterise $m_{wilting}$ using the equation $m_s = \frac{\ln(p)}{a_s t}$ assuming 1% survive after 2 days at 0% wilting fraction or $m_s = \frac{\ln(0.01)}{2\,(1-0.5)}$.
$\boldsymbol{c}_{moist}$	Critical soil moisture fraction, -	0.8	There is extremely little data is available on the negative effect of constant wet conditions, so both $\boldsymbol{c}_{moist}$ and $\boldsymbol{m}_{moist}$ were fit through iterative inspection of the distribution plot to reduce the tropical distribution.
$\boldsymbol{m}_{moist}$	Mortality rate per moisture stress, 1/d	10	

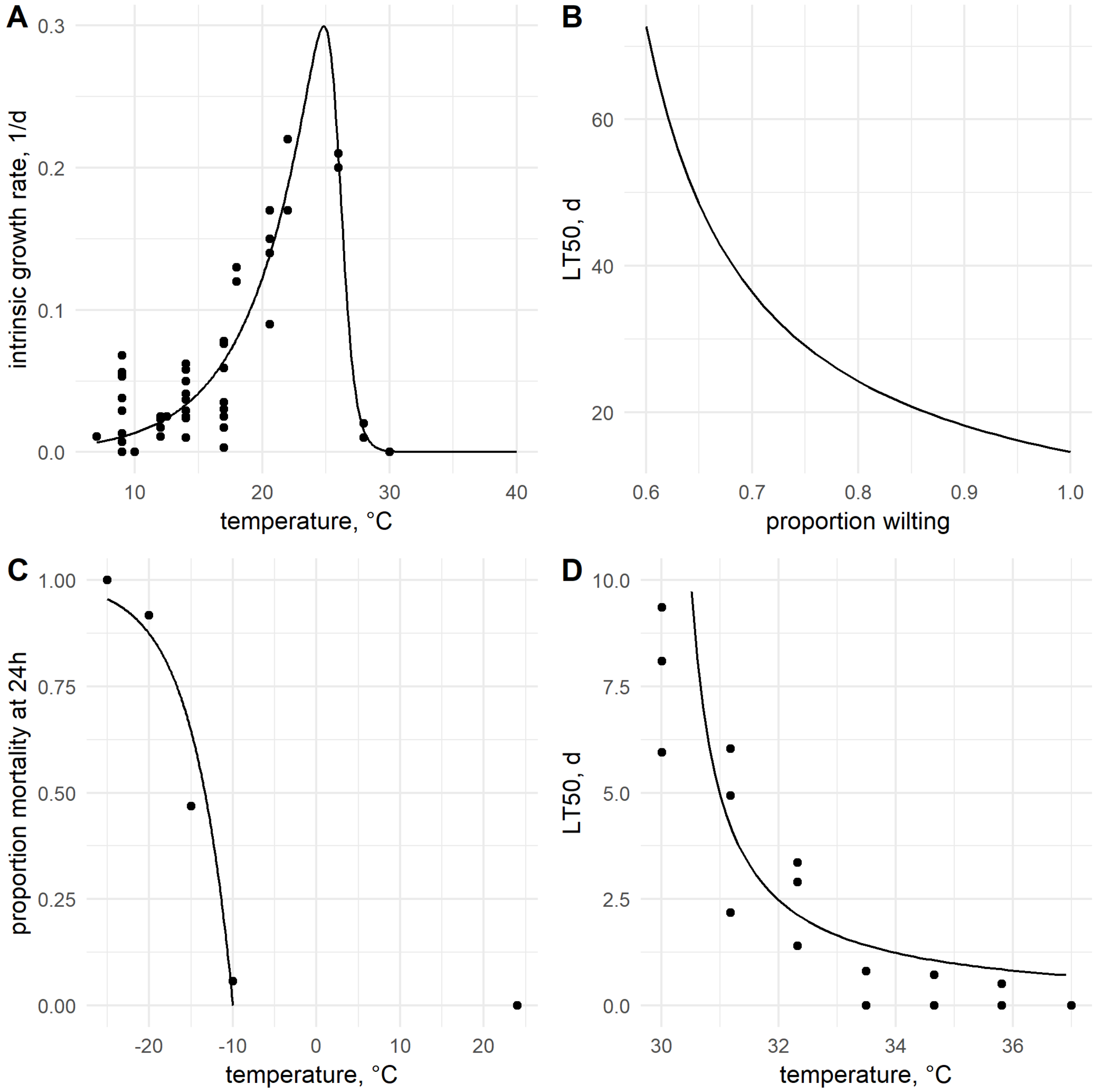
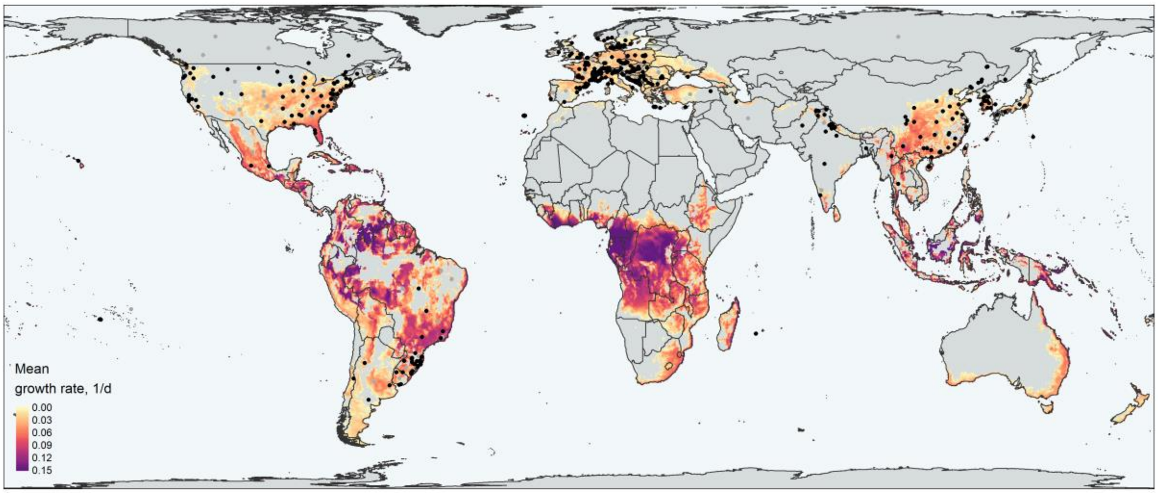


Figure 1. *Drosophila suzukii* population responses to temperature and soil moisture as estimated from available data (see Table 1). Intrinsic population growth rate is the rate of change in individuals per individuals per day (A). For desiccation (wilting), mortality rates are expressed as time in days to 50% mortality (LT50) (B). The for cold mortality, the proportion of individuals dead after 24 hours is shown (C) and for heat stress, mortality rates are expressed as time in days to 50% mortality (LT50) (D). See Table 1 for justification and source data.



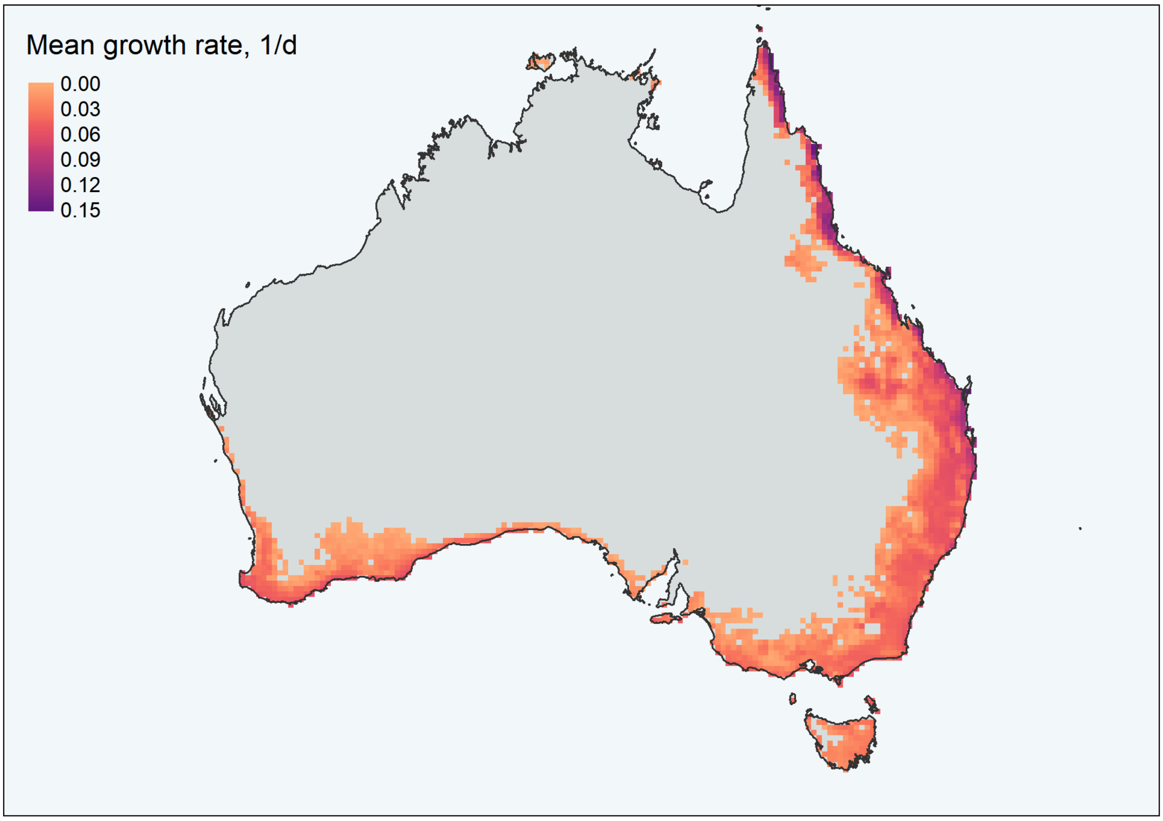


Figure 2. Top: Modelled mean annual intrinsic population growth rate of *D. suzukii* plotted against recently assembled occurrence data from Ørsted and Ørsted (2019) (black circles) and CABI (accessed January 2020) (black circles). Bottom: The same plot as above focussed on Australia predicting large areas of climatic suitability in Australia's south-east.

Short-ranged dispersal

Individuals can travel short distances (up to 9 km per generation) via flying adults (Tait et al. 2018), and long-distances, primarily through human-assisted dispersal (Adrion et al. 2014). Here we address short and long distance spread separately to improve computational tractability, and because, increasingly, research on stratified dispersal (Shigesada et al. 2002) suggests that different processes are underpinning the extremes of the "fat-tailed" probability density functions commonly enlisted to model biological dispersal (Nathan et al. 2012).

In short-ranged dispersal, a simple location dispersal kernel specifying the probability density of an individual migrating from cell i to j during a timestep can be defined by a negative exponential function of distance between cells ($d_{i,j}$):

$$f_{i,j} = \exp\left(-\frac{d_{i,j}}{a}\right)$$

where $d_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}$ where a is a parameter than be estimated from data (Table 2) (Nathan et al. 2012).

This probability density can be truncated and discretised for a neighbourhood of cells (S_i) within a finite step distance (d_S) from cell i where neighbourhood cell $s \in S_i \mid d_{i,n} < d_S$ assuming negligible short-distance migration beyond d_S.

The discrete probability of an individual migrating from cell i to s is thus given by:

$$p_{i,s} = \frac{f_{i,s}}{\sum_s f_{i,s}}$$

Long-distance dispersal

Long-distance dispersal is an important but contentious dispersal process as it can have profound impacts on dispersal rates (Kot et al. 1996) but is intrinsically difficult to quantify due to the large spatial scales at which it operates. Human-assisted dispersal has been implicated as a major contributor to long-distance dispersal (Suarez et al. 2001; Wilson et al. 2009; Bigsby et al. 2011; Chapman et al. 2017; Hudgins et al. 2017). Thus, we incorporate a module for human assisted spread, assuming long-ranged dispersal is proportional to human movement. We assume the probability of a human moving from occupied cell i to unoccupied cell j depends on distance ($d_{i,j}$), and the human population density at the origin H_i and destination H_j, and is proportional to $(H_i H_j)^b / (d_{i,j})^c$ (Bossenbroek et al. 2001) where b and c are exponents estimated from data (Table 2). Thus, the probability density of a long-distance disperser moving from cell i to j is given by.

$$g_{i,j} = \frac{(H_i H_j)^b}{(d_{i,j})^c}$$

This formula, often used to model human movement in geography (Thomas and Huggett 1980), is called the gravity model after Newton's equations relating the gravitational force between two bodies. To simplify and discretise the problem for cellular dispersal, we first down-sample the grid to a predetermined resolution. For each cell i we use the probability density function g to define a long-distance dispersal neighbourhood L_i with cell $l \in L_i$ for the n highest values of g so that low probability destinations are not considered.

The number of long-distance dispersers N_{LDD} leaving a cell is not constant across cells due to the heterogeneity in pest population size and human activity in each cell. The simplest function to account for this is:

$$N_{LDD} = d\ H\ N$$

where d is a free parameter constrained by $dH \leq 1$.
Long-distance dispersers are assumed to move in groups where group size is a uniform random variable between 1 and e, which is estimated from data (Table 2). This was not only more computationally efficient but captures groups of flies moving in contaminated produce (Maino et al. 2019).

The probability of a group of long-distance dispersers moving from cell i to cell l can thus be given as the multinomial distribution with the following probabilities:

$$p_{i,l} = \frac{g_{i,l}}{\sum_l g_{i,l}}$$

Allee effects

To capture Allee effects of migrants in a new range we introduce a final parameter f representing the threshold number of migrants required for permanent establishment, which is estimated from available data (Table 2). If the number of individuals in a cell are below f at the end of a time step, they are assumed to become extinct before the start of the next time step.

Gridded data, simulations, parameter estimated, and model evaluation

The Soil Moisture Active Passive (SMAP) data products derived from the SMAP satellite mission were used to estimate various climatic conditions relevant to habitat suitability (Entekhabi et al. 2010). In particular, we use SMAP Level 4 data products, which are model-derived value-added products that combine SMAP satellite observation with a land surface model and observations-based meteorological forcing data, including precipitation and temperature, to provide global gridded climatic and environmental data at the 9km resolution (grid cell) every 3 hours from April 2015 to present (Reichle et al. 2017). Three data fields are used to define climatic stressors including 'surface_temp': mean land surface temperature (K), and 'land_fraction_wilting': the fractional land area that is at wilting point based on soil moisture at 0-5 cm (m^3 m^{-3}) and estimated soil type.

Using gridded SMAP climatic data from 2015 to 2018 and the parameters defined in Table 1, for each month the mean daily stress limited growth rate $r - \sum_s f(s, s_c) m_s$ is calculated using 3-hourly timesteps which are then used to estimate intrinsic population growth across the world for each month. While carrying capacity is will vary based on climate and host-availability, for simplicity, we assume a carrying capacity of 1 billion individuals per grid cell.
Human population densities were estimated using The Gridded Population of the World (GPW) which is a continuous global raster surface of the distribution of human population densities (CIESIN (Center for International Earth Science Information Network) 2016).

Simulations were run at a 9 km grid cell resolution and monthly steps. Parameters in Table 2 were restricted to feasible ranges and then fitted to national spread data in the United States from 2008 to 2014 until the deviance (zero-one loss) of observed and predicted yearly state-level occupation was minimised (Ørsted and Ørsted 2019). States with area below 1000 km^2 (Washington DC) and states separated from the mainland states (Hawaii and Alaska) were not considered. Due to model stochasticity, 500 replicated simulations were used to calculate a mean loss value which is used by a simulated-annealing optimisation procedure to find the parameter set that minimised deviance. To account for imperfect detection, a state was not considered occupied until over 1 million individuals had accumulated in any cell. California represents the first known detection of *D. suzukii* in the continental United States (Bolda et al. 2010), thus simulations are initialised with 1 million individuals (the assumed detection threshold) in a single cell at San Jose in 2008. To enhance computational speed, human dispersal was calculated on coarser grid (mean of each 8 x 8 grid cells [cluster]) with the top 100 highest probability destinations for each cluster retained. The final-destination was then randomly allocated to a grid-cell within each 8 x 8 cluster. To intuitively visualise the trade-off between human population density and distance from origin, the fitted probability density of long-distance dispersal of migrants originating from Charlotte (North Carolina) to destinations spanning a transect to New York city is shown in Figure 3.

To minimise the risk of overfitting, we validated the model to independent data on the spread of *D. suzukii* in Europe. Cross validation of model fit is necessary to ensure the applicability of the model outside of the training data. Using the fitted parameters, spread is similarly simulated in Europe from 2008 to 2014 initialised at first detection points in Spain and Italy in 2008 (Ørsted and Ørsted 2019) and contrasted against presence-absence data at the country level. European countries with area below 1000 km^2 (e.g. Monaco) were removed from this comparison.

To evaluate the quality and contribution of separate model components (Table 3), we parametrise four additional formulations: three alternately removing short distance dispersal, Allee effects, and human dispersal; and one replacing the climate-driven growth model with a simple logistic growth model, defined as $\frac{dN}{dt} = \left(1 - \frac{N}{K}\right) r_c N$.

Finally, this model is used to estimate rates of spread in 6 years following an incursion into Australia.

Results

Using biological parameters measured in laboratory studies, the resulting climate-based population growth model successfully captured the global distribution of *D. suzukii,* which provides confidence when projecting to novel ranges, such as Australia (Figure 2). A large portion of Australia's south-eastern range, as well as some restricted areas in western Australia were predicted to have climates that will support *D. suzukii* populations (Figure 2).

Parameterised simulations of spread in the United States showed a good fit for observed movements, including early jumps between the west and east coast that occurred via human dispersal (Figure 3). The full model that included all dispersal subprocesses produced the best predictions for the United States, with an accuracy of 83.2% (Table 3). When the same model was applied to the validation dataset of the European incursion, the model predicted 73.0% of the observed spread.

Spread in Europe was estimated to proceed faster compared with United States due primarily to mean human population densities of over 1.6 times greater the United States. In three years, *D. suzukii* was estimated to have covered 4. 56 million km^2 in Europe compared with 1.03 million km^2 in the United States.

The Allee module had the smallest impact on predictability, reducing accuracy by only 0.2% and 0.3% in the United States and Europe respectively. This small founder effect is also reflected in the low estimated threshold for establishment of 22 individuals per grid cell. Local dispersal had a larger impact on predictability, reducing accuracy by 1.5% and 2.0% in the United States and Europe respectively. Replacement of the climate-dependent growth module with a constant growth rate module caused a similar decrease in accuracy in the United States (2.3%) but a much larger decrease in the European data set used for validation (11.5%).

Removal of the human-mediated dispersal module had the largest impact on predictability in the United States with a reduction in accuracy of 24.5%. The comparatively smaller reduction of 2.6% in the accuracy of European dataset reflects the more homogenous distribution of human populations across the European continent. Fitted parameters were used to quantify the long-distance migration probability from a given location, i.e. the trade-off between distance from origin and the size of the human population (Figure 3C). In a transect from Charlotte (North Carolina) to New York city, long-distance dispersers were found to be half as likely to migrate to the city of Philadelphia compared with the closer but smaller city of Greensboro.

Table 2. Dispersal module parameter, fitted values, and pre-optimisation bounds for the full-model

Module	Parameter (description)	Fitted value	Bound justification

		(Bounds)	
Local dispersal	**a** *negative exponential coefficient*	0.0125 [constant]	Parameter was fixed on the assumption that *D. suzukii* can move 5m per day on average (Drummond et al. 2019). Given bounds, the upper bound is always chosen by the optimiser.
Human dispersal	**b** *population density exponent*	1.075 [0, 3]	Due to the exponential effect of this parameter, the upper limit is set at an arbitrarily high exponent.
	c *distance exponent*	1.429 [0, 3]	Due to the exponential effect of this parameter, the upper limit set is at an arbitrarily high exponent.
	d *propagule pressure coefficient*	8.703×10^{-9} $[0, 10^{-10}]$	The upper limit assumes that at the maximum population of human and *D. suzukii*, there will be approximately 100,000 long-distance migrants each time step.
	e *maximum group size*	3.264×10^{4} [10, 10,000]	There is little available data on the amount of *D. suzukii* transported in single events. We allowed for variation over three orders of magnitude.
Allee	**f** *minimum viable population*	22 [2, 1000]	Two individuals are the minimum for a sexually reproducing species.

Table 3. Model accuracy on training set (US) and cross-validation set (EU) across alternate models with respective submodules removed. Mean loss is the mean value of the zero-one loss function across replicate simulations, while accuracy is mean proportion of presence-absences through time correctly predicted.

Model	Components driving model	Mean loss (US)	Accuracy (US)	Mean loss (EU)	Accuracy (EU)
Full	Human dispersal, local dispersal, Allee effects, climate driven growth	48.3	83.2%	94.6	73.0%
No local dispersal	Human dispersal, local dispersal, Allee effects, climate driven growth	52.8	81.7%	101.9	71.0%
No Allee effect	Human dispersal, local dispersal, climate driven growth	49.0	83.0%	96.0	72.7%
No human-mediated dispersal	Local dispersal, Allee effects, climate driven growth	116.0	59.7%	104.0	70.4%
No climate	Human dispersal, local dispersal, Allee	54.9	80.9%	135.2	61.5%

	effects, logistic growth				

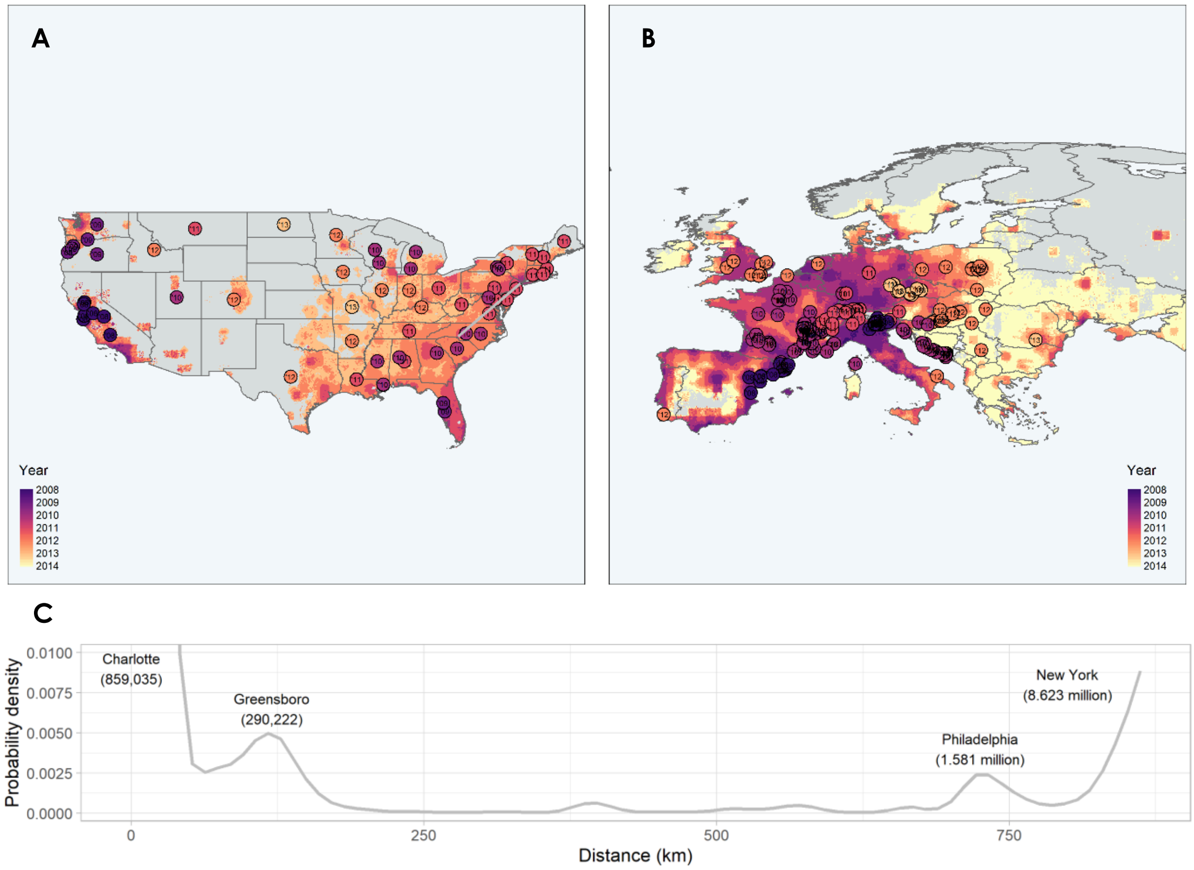


Figure 3. Predicted and observed establishment of *Drosophila suzukii* in the United States (**A**) and Europe (**B**). The full-model was parameterised against spread data from the United States and cross-validated against data from Europe. Circles denote distribution data compiled by Ørsted and Ørsted (2019) with the gradient inside the circles indicating the observed year of establishment, while the gradient outside the circles denote the model predictions of the average first year of establishment in each cell across replicate simulations. The probability density of long-distance dispersal destinations is illustrated in a panel along a transect from Charlotte to New York (**C**). The location of this transect is indicated by the grey line in panel A. Human population sizes of respective cities are shown in brackets.

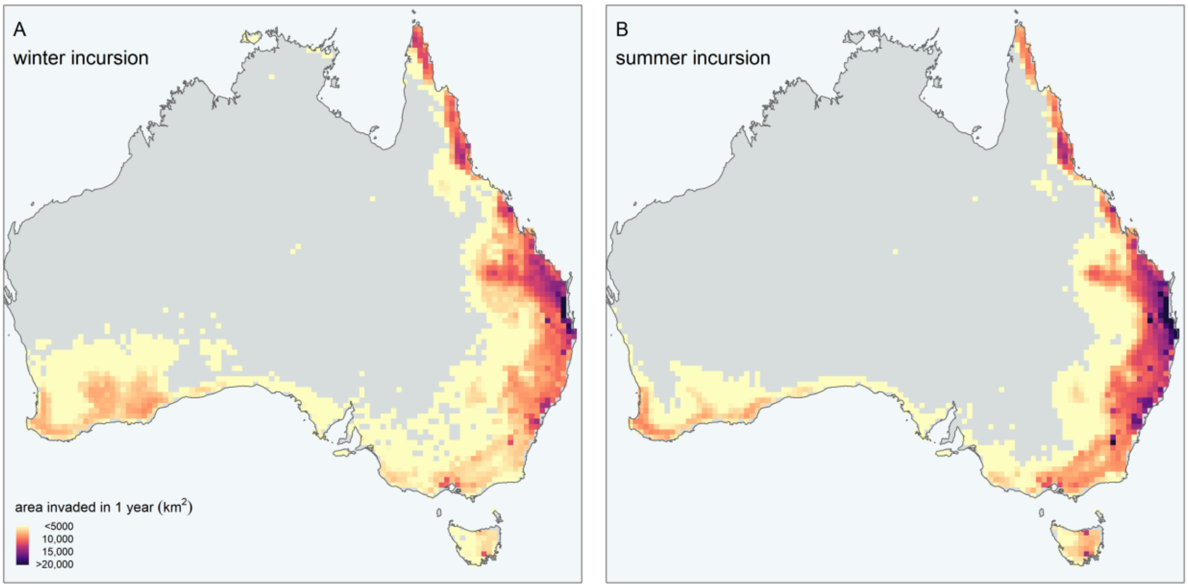


Figure 4. For each grid cell an incursion is simulation with the mean predicted area invaded by *D. suzukii* in one year shown by the colour gradient. The mean predicted area is estimated from 5 replicated simulations. Incursions were commenced in both July (**A**) and January (**B**).

Incursions into Australia, like those into Europe and the United States, were predicted to spread rapidly. For example, an incursion into the eastern Australian city of Brisbane resulted in a predicted occupied area of 15,763 km^2 (for incursions commencing in January) and 21,254 km^2 (for incursions commencing in July) after only one year from commencement. More generally, simulated incursions across Australia highlight that eastern coastal regions, particularly those near cities would lead to fastest spread, with areas of 10,000 - 20,000 km^2 invaded after one year commonly predicted (Figure 4). An effect of seasonality on spread rate was also apparent with summer incursions tending to favour faster spread in more temperate climates compared with winter incursions (Figure 4).

Discussion

In this first study on the drivers of the global invasion of *D. suzukii*, human-assisted dispersal emerged as the dominant explanatory factor. Combined with local population dynamics, short-ranged spread, and to a lesser extent, Allee effects, a high degree of predictability was found in global spread patterns. This was surprising in light of previous studies that found inherent stochasticity of dispersal processes can place strong limits on predictability (Ehrlich 1986; Clark et al. 2003; Melbourne and Hastings 2009). A logical conclusion is that the predominance of human-mediated dispersal pathways in modern biological invasions can overwhelm the inherent stochasticity of dispersal processes rendering them predictable. The importance of human-assisted dispersal in the spread of *D. suzukii* will have important biosecurity implications for Australian preparedness programs. Other recent studies have arrived at similar conclusions regarding the increased role of human-assisted dispersal in modern invasions across diverse systems (Suarez et al. 2001; Wilson et al. 2009; Bigsby et al. 2011; Chapman et al. 2017; Hudgins et al. 2017).

The forecast of spread rates for simulated incursions across Australian continent reveal a logical means for prioritising surveillance efforts, i.e. a focus on locations and periods of time most likely to facilitate rapid spread. In addition, in the event of a detection, the predicted spread rate for each location offers an approach for adjusting the area that should be delimited for pest freedom, i.e. larger areas will need to be limited in areas conducive to more rapid spread. While monitoring and surveillance programs that consider the unique biology of *D. suzukii* will likely help to mitigate impacts, the costs of undertaking surveillance and quarantine programs need to be placed in the context of costs of pest impact to industry. The rapid spread rate predicted following incursions of *D. suzukii* into Australia, particularly into eastern coastal regions surrounding large cities, suggest eradication efforts are likely to difficult and expensive. Effective pre-border biosecurity and quarantine programs, and a swift transition to management is likely to be the most effective strategy for Australia (and, indeed, other countries were *D. suzukii* has not yet established). This requires ongoing extension and education efforts, which should ideally prioritise those areas found to have the greatest risk of establishment and spread.

The apparent predictability of biological invasions due to anthropogenic processes offers a promising way forward for quarantine and surveillance programs. Despite advances in monitoring methodologies, current monitoring practices for *D. suzukii* cannot be used as an early warning tool (Walton et al. 2014), as one fly detected in a monitoring trap translates to approximately 71 individuals per hectare, which is above the intervention threshold for pest management (Kirkpatrick et al. 2018). Surveillance for other biosecurity threats are likely to face similar challenges. A central constraint to improving biosecurity surveillance is the lack of objective risk analyses methods to identify the most appropriate monitoring targets (Kean et al. 2008). Predictive models that incorporate common mechanisms underpinning spread can support these efforts. Due to its modularity it may also be specialised to answer more specific and applied research questions, such as estimating expected production losses, cost-benefit analyses of interventions, and quarantine strategies that depend on context (human-population, suitability, and economic connectivity).

A simplifying assumption of the model is that *D. suzukii* is unlikely to be limited by non-crop hosts. In Australia, this assumption is defensible on basis of the wide distribution some key non-crop hosts. In supplementary figure S1, the wide distribution of *Rubus* species demonstrates a wide overlap with the predicted range of environments climatically suitable for *D. suzukii* in Australia. While these *Rubus* records include highly suitable and widespread host species such as wild blackberry, *Rubus occidentalis*, *D. suzukii* will be able to utilise other less suitable non-crop hosts, such as some species belonging to *Prunus*, particularly, with wild hosts prone to damage (e.g. from birds) or becoming overripe, which will both increase the suitability for oviposition and larval development.

The rapid spread and establishment of *D. suzukii* predicted for Australia assumed that the same processes operating in the United States and Europe are valid in an Australian context. However, Australia's stringent domestic quarantine processes may result in slower spread and establishment than that observed overseas. However, this relies on existing biosecurity measures (e.g. for Tephritid fruit flies) being relevant for *D. suzukii*. The ability of *D. suzukii* to persist in colder environments than other major pest fruit flies will pose unique problems for existing domestic fruit fly quarantine programs. A monitoring and surveillance programs that considers this unique biology of *D. suzukii* will likely further mitigate impacts but the associated costs need to be placed in the context of impact potential in the absence of surveillance and quarantine. The framework developed here will next be used to explore the unique impact potential of *D. suzukii* and the relative cost-benefits of surveillance and quarantine programs.

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Hort Innovation

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Supplementary figures

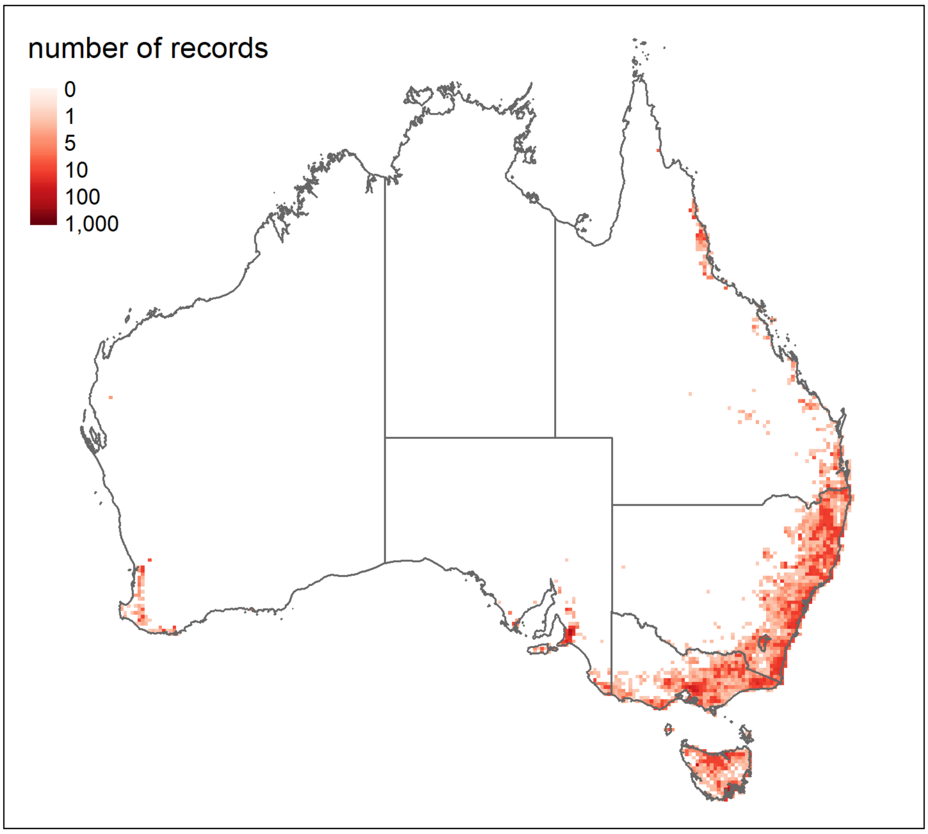

Figure S1. The spatial distribution of *Rubus sp.* reports on the Australian Living Atlas database suggest that the distribution of non-crop hosts is unlikely to be a limiting factor in the spread of *D. suzukii*.

The impact potential of spotted-wing drosophila in Australia

Confidential Report

June 26, 2020

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Executive Summary

The spotted wing drosophila (*Drosophila suzukii*) has emerged as an international pest that poses a threat to Australia's significant horticultural production. While presently absent from Australia, several studies predict highly suitable conditions for establishment and spread across Australian farming regions. However, the potential impact of *D. suzukii* in Australia has yet to be estimated, which limits the prioritisation of quarantine systems and incursion responses.

Here, we conduct the first international literature review on crop losses where mean reported crop losses varied most strongly with commodity type with impacts typically within 20-50% in the first 2 years following establishment and decreasing to under 10% after 6 years. Following this review, we use a spatially explicit simulation framework to estimate the potential economic impact of *D. suzukii* to Australian horticulture. The framework includes modules for population establishment, growth, and spread, which are overlaid onto the spatial distribution of susceptible horticultural productivity to estimate impacts through time. Impacts are calculated separately for each jurisdiction and at the national level for a variety of incursion locations.

The estimated impacts of *D. suzukii* in Australia were substantial, particularly for southern soft-fruit growing industries. Depending on the incursion location, predicted national accumulated impacts after three years varied from $16.6 – 61.3 million, reflecting rapid spread into its suitable range. Most impacts were predicted to occur in south-eastern Australia, particularly Queensland and Victoria, due to substantial strawberry, cherry and caneberry growing regions. Importantly, impacts did not necessarily scale with the size of the affected industry but also depended on the environmental suitability and isolation of each industry's production regions. These same factors also led to the incursion location associated with the highest impacts varying for each industry, which may lead to different biosecurity priorities for each industry.

Introduction

Spotted winged drosophila, SWD, (*Drosophila suzukii*) is a new and significant pest of a range of soft, thin-skinned fruits including blueberries, caneberries (e.g. blackberries, raspberries, loganberries and youngberries), cherries, strawberries, summerfruit, and grapes. While *D. suzukii* was first described from Japan in 1931 and is present throughout several Asian countries, its potential importance as a production pest was only fully realised after incursions into the mainland US and Europe in 2008 (Bolda et al. 2010; Cini et al. 2012). In contrast to most Drosophila species, *D. suzukii* is capable of laying eggs (ovipositing) into ripe and ripening, undamaged fruit (Atallah et al. 2014). The ability of *D. suzukii* to puncture soft-fruits was conferred through the evolution of a "serrated ovipositor", which, compared to ovipositors of other related Drosophila, is larger in area with an increased length to width ratio, and has modified ovipositor bristles that form a "serrated" edge and a sharper ovipositor tip. Due to the apparent insignificance of other *Drosophila* as pests in commercial production, initial reports of fruit damage in the US were largely overlooked, allowing the pest to expand its geographical range unchecked (Hauser 2011). The observed impact of *D. suzukii* in the US and Europe has been highly variable. Losses as high as 80% have been reported in caneberries, strawberries and cherries, however 20-40% losses may be more common (Bolda et al. 2010). Larval feeding causes the fruit to collapse around the oviposition site with the oviposition site vulnerable to secondary attack by pathogens and other insects (Hauser 2011). Thus, damage occurs through direct yield loss and reduced marketability of fruit with no practical option for treating infested commodities or redirecting them to alternative markets.

Australia is currently free of *D. suzukii* but fruit industries, valued at AUD$4.8 billion, remain highly vulnerable to an incursion (HIA 2019). Independent studies modelling the potential global distribution of *D. suzukii* have concluded that there are substantial regions of Australia with high climatic suitability (Dos Santos et al. 2017; Ørsted and Ørsted 2019; Maino 2020). Despite natural isolation and a rigorous approach to biosecurity, Australia's Department of Agriculture has identified the lack of an established *D. suzukii* control program could result in significant impacts on horticultural industries (Department of Agriculture Fisheries and Forestry Biosecurity 2013). Even after the transition to management, *D. suzukii* has caused major disruption to existing integrated pest management programs in the United States through a reliance on broad spectrum pesticides (Van Steenwyk and Bolda 2014). To improve industry preparedness and responses to pest incursions, understanding spread and impact processes are required before designing monitoring and management strategies for risk mitigation. Due to the well documented recent incursion of *D. suzukii* into the United States and Europe, there exists substantial data available to refine knowledge on continent-scale establishment, spread and impacts of *D. suzukii*.

Here, we quantify probable unmitigated impacts in terms of crop losses to Australian production industries resulting from the spread and establishment of *D. suzukii*. We define "unmitigated impacts" as the direct cost in terms of lost production associated with the predicted spread and establishment of *D. suzukii* without mitigation (e.g. implementation of surveillance, quarantine, or management programs for *D. suzukii*). More specifically we aim to answer the following research questions: 1) what range of values for crop losses have been reported overseas for different commodities; 2) are there regional differences in reported crop losses; 3) what is the spatial distribution of potentially affected commodities in Australia and 4) how will unmitigated impacts to Australian production industries accrue through space and time under several plausible incursion scenarios and for different industries.

Methods

To estimate regional and cross-commodity variation in risk associated with *D. suzukii* we conducted an international literature review of all impacts (in terms of reported proportion crop loss) for affected commodities (Appendix 1). These included reports published in scientific publications as well as industry reports. Special attention was paid to the region in which the data was reported in order to assess any regional variation in impacts. Wherever reported, the spatial coordinates of the report were captured, otherwise an approximate location was inferred from the reported region, which was frequently only at the state or regional level. Wherever a range of impacts was reported, the mid-point impact value was taken. Variation in reported impacts (for commodities with more than 5 reports) was explored using a quasi-binomial regression on reported crop losses with explanatory variables including commodity type, latitude (degrees), and area of affected commodity grown (United States Department of Agriculture 2019).

To analyse the distribution of susceptible commodity production in Australia, we utilised commodity value data from the Australian Bureau of Statistics Agricultural commodity census (ABS 2016). The following commodity categories were taken to be affected by *D. suzukii* based on the literature review: strawberries, cherries, blueberries, plums, nectarines, peaches, grapes (all other uses – i.e. not wine), apricots, and caneberries (and all other berries not elsewhere classified). The data were reported at the regional level for Statistical Area Level 2 (SA2) for predefined polygons rather than a grid of locations (Figure S1).

To construct gridded estimates of the production value of affected commodities, the previous ABS production volume estimates were combined with Catchment Scale Land Use of Australia data (ABARES 2018), which provided high spatial resolution (50 m) of relevant land usage types, including irrigated perennial horticulture, irrigated seasonal horticulture, and intensive horticulture. For each SA2 statistical division, the production value of commodities was distributed evenly across all horticultural grid cells according to the proportion of each cell under horticultural cultivation. This resulted in a gridded distribution of annual production values for affected horticultural commodities across Australia (Figure S2). To estimate impacts through time, gridded production values were overlaid with a gridded spread model of *D. suzukii* (Maino 2020). This model simulated *D. suzukii* population growth using laboratory studies and climatic data (temperature and soil moisture availability). Populations in each cell were linked to other cells through two kinds of dispersal: passive dispersal through insect flight to adjacent cell; and human-mediated jumps that depend on the size of human populations at the source and destination cells. Density dependent effects required new migrants into an unoccupied cell to surpass a threshold before establishment occurred. The model was parameterised and tested against rates of spread observed in Europe and the United States mainland following the initial incursion in 2008 explaining 70-80% of regional-level variation in spread rates through time providing greater confidence when extrapolating international spread patterns to Australia.

Impacts were explored in several ways in order to assess the importance of various assumptions to impact estimates. In order of ascending complexity, impacts are first assumed to be a fixed proportion of susceptible commodities produced annually. Following this, estimated impacts are then assumed to include only those areas in which SWD is predicted to be suitable for establishment. Next, estimated impacts for each location are further reduced by the proportion of the year in which SWD population growth is estimated to be negative. Finally, accumulated impacts following a single incursion event and subsequent spread is estimated with annual impacts averaged over six years following the incursion.

To explore the different incursion scenarios, initial outbreaks were simulated (and followed across three years) in capital cities Melbourne, Adelaide, Hobart, Brisbane, Sydney and Perth, which represents a range of different climates, human population densities and surrounding production industries. To focus on the role of spatial variation in crop production and temporal environmental suitability, crop losses were assumed to be 10% of production value. The fixed value of ten percent was taken as a reasonable estimate across different commodities under management (acknowledging bias towards the reporting of high losses as minor losses may go unnoticed or unreported), and to simplify the wide variation that has been observed even within commodities (Table 1). To adjust this assumption, impact estimates can be easily scaled (e.g. multiply estimated impacts by two if assumption is 20% crop loss).

Results

The international literature review resulted in 244 reports on 16 commodities (Table 1), where the top 6 most reported commodities in descending order were blueberries, raspberries, blackberries, strawberries, table grapes, and sweet cherries. The number of reports did not necessarily correspond with the level of reported crop loss (Table 1). Notably, there was large variation in the estimated rate of impacts, both within and between commodities (Figure 1 and Table 1). For example, infested raspberries exhibited a mean reported crop loss of 31%, which was higher than strawberries at 9.8%, but also exhibited more variation with a reported range of 0-80% and 0-100% respectively (Figure 1). The quasibinomial regression of crop losses in the United States against compiled covariates (Figure S3) revealed that commodity type explained most of the variance of all explanatory factors tested (15%), followed by years since SWD established in region (13%), and finally latitude (8%) (Table 2). Mean impacts were estimated to vary from 15-50% (depending on the commodity) in the first 2 years following establishment but decreased to under 10% after 6 years (Figure 2). Controlling for commodity effects, the odds of fruit loss due to *D. suzukii* decreased by 39% for each year following initial outbreaks. In total, the unexplained variance in impacts remained high with only 36% of variance in crop losses explained by the model covariates (Table 2).

Table 1. Impact potential of *Drosophila suzukii* on affected commodities in terms of international collated reports of proportions crop value lost due to firect feeding damage. The table is ordered by the number of total crop loss reports. Australia's total production value of each commodity is provided.

PLANT NAME	COMMON NAME	VALUE* ($ MIL.)	REPORTED CROP LOSS FROM OVERSEAS			N	SOURCES
			mean	min	max		
VACCINIUM SP.	blueberries	$193.60	14%	0%	100%	56	(Cowles 2011; Grassi et al. 2011; eFly SWD working group 2012, 2014, 2015; Van Steenwyk and Bolda 2014; de Ros et al. 2015; Del Fava et al. 2017)
RUBUS SP.	raspberries	$141.53	31%	0%	100%	52	(Bolda et al. 2010; Cowles 2011; Grassi et al. 2011; eFly SWD working group 2012, 2014, 2015; de Ros et al. 2015; Sward et al. 2016; Del Fava et al. 2017; Farnsworth et al. 2017)
RUBUS SP.	blackberries	$23.31	24%	0%	100%	45	(Bolda et al. 2010; Grassi et al. 2011; eFly SWD working group 2012, 2014, 2015; de Ros et al. 2015; Del Fava et al. 2017)
FRAGARIA SP.	strawberries	$506.50	8%	0%	80%	45	(Bolda et al. 2010; Grassi et al. 2011; eFly SWD working group 2012, 2014, 2015; de Ros et al. 2015; Del Fava et al. 2017)
VITIS SP	table grapes	$534.40	7%	0%	35%	23	(Cowles 2011; eFly SWD working group 2012, 2014, 2015)
PRUNUS AVIUM	sweet cherries	$120.70	17%	0%	90%	17	(Bolda et al. 2010; Grassi et al. 2011; eFly SWD working group 2012, 2014, 2015)
PSIDIUM CATTLEIANU	guava	NA	74%	74%	74%	1	(Lasa et al. 2017)
PRUNUS ARMENIACA	apricot	$29.90	35%	35%	35%	1	(Grassi et al. 2011)
PRUNUS DOMESTICA	plum	$74.80	20%	20%	20%	1	(Escudero et al. 2011)
PRUNUS PERSICA	peach	$112.56	10%	10%	10%	1	(eFly SWD working group 2012)
PRUNUS PERSICA VAR. NUCIPERSICA	nectarine	$168.84	10%	10%	10%	1	(eFly SWD working group 2012)
DIOSPYROS KAKI	persimmon	$10.50	1%	1%	1%	1	(Kanzawa 1939)
ACTINIDIA	kiwi	$20.40	0%	0%	0%	1	(Minister for Primary Industries 2012)
MALUS DOMESTICA	apple	$441.50	0%	0%	0%	1	(Department of Agriculture Fisheries and Forestry Biosecurity 2013)
RIBES	currants	$27.00	0%	0%	0%	1	(Grassi et al. 2011)
VITIS	wine grapes	$971.0	0%	0%	0%	1	(eFly SWD working group 2012)

* Horticultural Statistics Handbook 2016-17

Table 2. Analysis of variance of factors affecting reported proportion crop loss associated with *Drosophila suzukii* in the United States.

Explanatory variable	df	Deviance	Resid. df	Resid. dev.	p
Time since first detection	1	10.7	232	71.3	<0.001
Commodity	5	12.1	227	59.2	<0.001
Latitude (decimal degrees)	1	6.6	226	52.7	<0.001

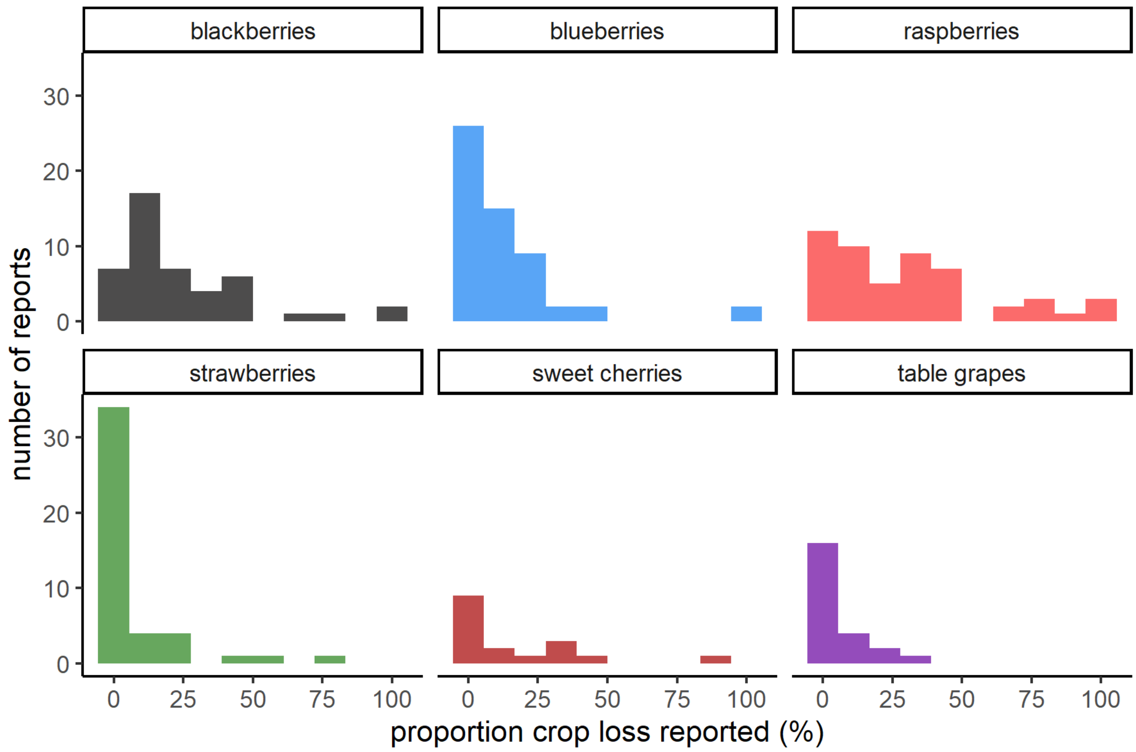

Figure 1. The frequency of proportion crop loss reported for affected commodities with over 5 reports following an international review. Reported proportion crop loss shows large variation between commodities and within commodities. The complete data set of reported crop losses and the data source is available in Appendix 1.

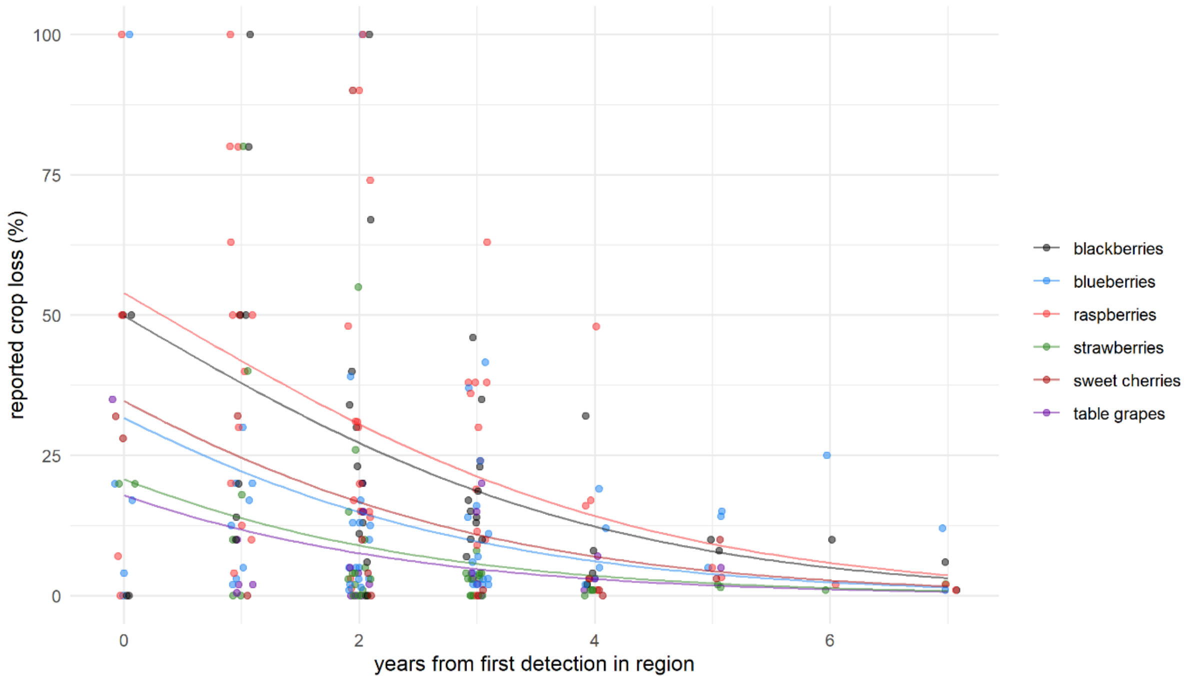

Figure 2. Reported proportion crop loss caused by *D. suzukii* generally decreases across years following initial establishment, highlighting the probable effect of increased familiarity and improved pest management practices. To show overlapping data, points are slightly offset along the horizontal axis.

In descending order, the largest industries of vulnerable commodities were table grapes ($408.3 mil.), strawberries ($265.1 mil.), cherries ($150.3 mil.), blueberries ($144.3 mil.), nectarines ($71.6 mil.), peaches ($57.5 mil.), plums ($38.9 mil.), caneberries and other berries ($31.1 mil.), and apricots ($20.2 mil.) (Figure 3A). In descending order, the sum of the value of affected commodities in each state were as follows: Victoria ($586.1 mil.), New South Wales ($202.2 mil.), Queensland ($201.9 mil.), Tasmania ($107.3 mil.), Western Australia ($72.4 mil.), South Australia ($65.1 mil.), and the Northern Territory ($1.3 mil.) (Figure S1).

To explore how impact estimates were affected by model assumptions, calculations from models of increasing complexity were compared. Assuming a simple proportion (10%) of gross production of susceptible commodities resulted in an estimated $136.0 million of annual impacts (Figure 3A and 4A). Assuming impacts were restricted to regions with climatic conditions that support viable populations (more than 4 months positive population growth per year) led to an estimate of $109.9 million of annual impacts, with the southern half of Australia categorised as suitable for *D. suzukii* (Figure 3B and 4B). Assuming impacts are scaled by the proportion of the year over which the pest is active resulted in $83.3 million of annual impacts with south-eastern coastal regions of Australia supporting positive population growth throughout most of the year with generally lower suitability predicted further inland (Figure 3C and 4C). Assuming impacts are calculated from 10 replicate incursions event beginning in Melbourne and simulated over 6 years, resulted in an average annual impact of

$34.7 million ($2.1 mil. in the first year and $63.4 mil. during the sixth year following the incursion) with the predicted eastern range occupied by the end of the simulation (Figure 3D and 4D). Due to the predicted widespread invasion of *D. suzukii* after 6 years from invasion (Figure 3D), the following analysis considers a three-year time span for impacts to accumulate.

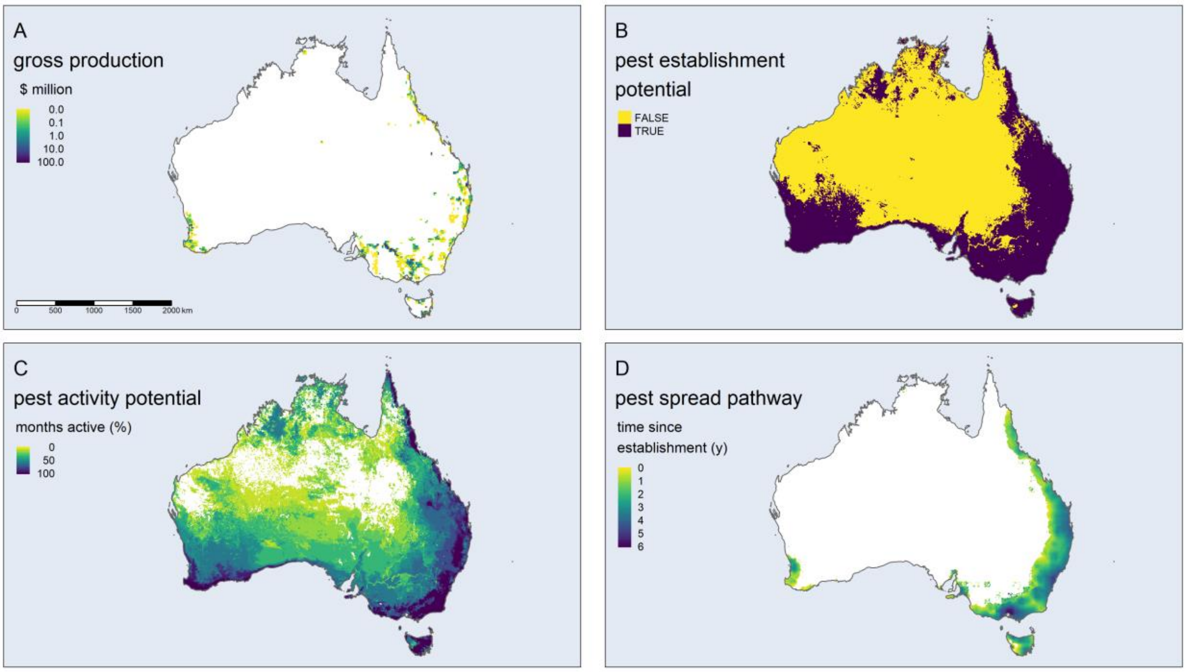

Figure 3 Potential industry impacts can be estimated with different models of that consider different processes. Impacts will depend on the local value of susceptible fruit crops as reported in the main text (A). Impacts will also depend on climatic conditions that support pest establishment (B). Impacts may also consider the proportion of the year over which the pest is active (positive population growth potential) (C). And finally, impacts may depend on pathways by which the pest is likely to spread, in this case, following a simulated Melbourne incursion (D).

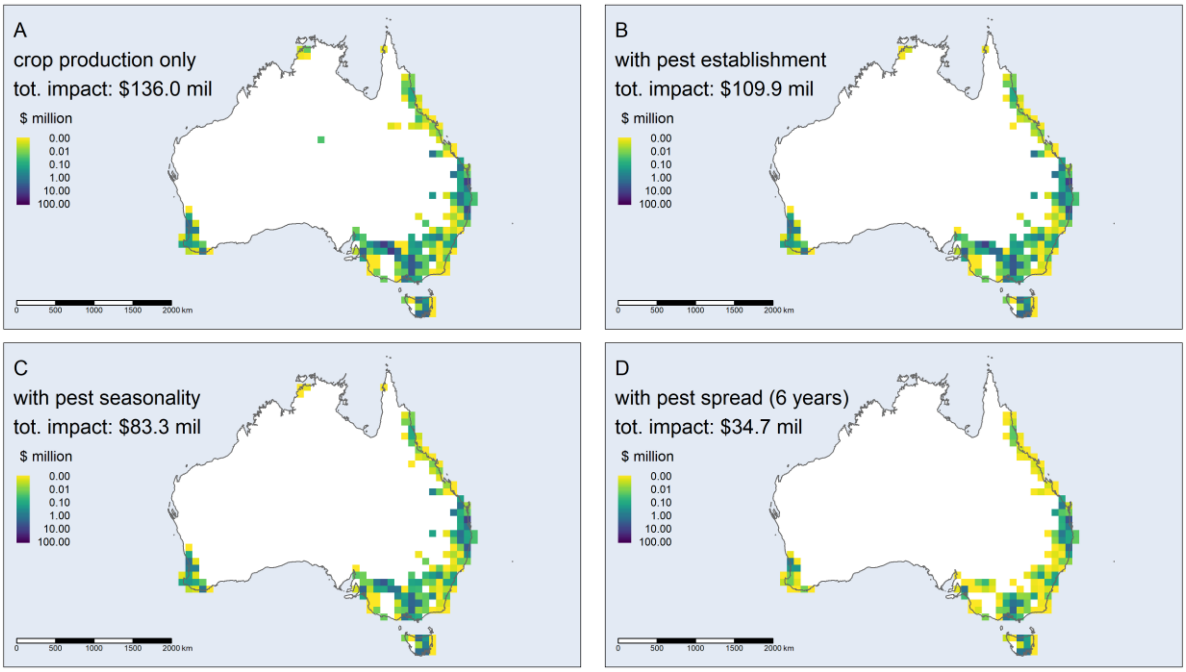

Figure 4. Annual pest impacts estimated with incremental model complexity and differ based on whether impacts: 1) are assumed to be a simple proportion (10%) of gross production of susceptible commodities (A), 2) are also restricted by climatic conditions that support population growth (B), 3) are also scaled by the proportion of the year over which the pest is active (C), and 4) are scaled by the mean predicted years established following a Melbourne incursion with impacts averaged over 6 years (D).

Predicted impacts the first three years following incursions were substantial across all incursion scenarios (Figure 5). Variation in accumulated impacts could be seen across incursion locations and commodities, which ranged from $16.6 – 61.3 million (Figure 5). Pooling all affected commodities, Brisbane was predicted to see the fastest accumulating and total national impacts due to its climatic suitability, large affected industries, and proximity to other large populations facilitating spread (Figure 5). Incursions into Sydney saw the next most rapid initial accumulation of impacts but was then overtaken by the Hobart incursion simulation.

The effect of incursion location depended on the commodity considered. For example, national cherry production was most vulnerable to a Tasmanian incursion. While national nectarines, plums, and peach production was most vulnerable to a Perth incursion (Figure 5). Impacts did not necessarily correspond to the size of the industry with impacts to strawberries predicted to see higher impacts than table grapes despite their smaller contribution to total soft fruit production (Table 3). Indeed, at the jurisdiction level, Queensland saw the largest impacts at $33.28 million after 3 years accounted for mostly by strawberry and blueberry production. Interestingly, significant table grape production in the Sunraysia region in north-western Victoria, was not predicted to be impacted within three years of any of the incursions from capital cities. A supplementary simulation (Appendix 2) simulating an incursion beginning in Mildura, showed that initial impacts would be large but that populations would not persist permanently.

Within jurisdictions, incursions at capital cities led to the greatest impacts in all cases, compared to other local incursions (Table 3). The closest exception to this was Devonport, which saw nearly as large an impact for Tasmanian soft fruit industries ($12.88 million) compared with Hobart ($13.10 million).

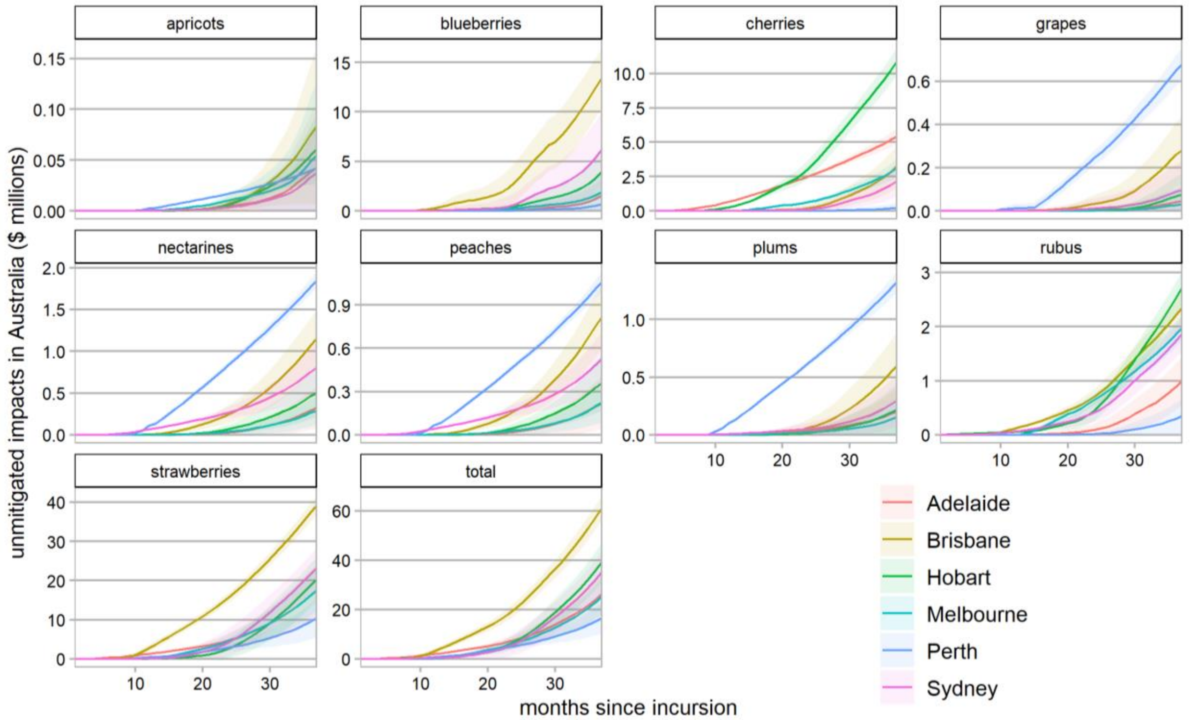

Figure 5. Accumulated national impacts through time dependent on incursion and commodity production location. A developed spread model for *Drosophila suzukii* (Maino 2020) which was able to account for: environmental conditions on *D. suzukii* population growth, short-ranged dispersal, and human assisted dispersal was extended to calculated impacts through time following different incursion scenarios. Incursion scenarios were conducted for key locations to explore the impact of incursion location to total estimated impacts. Simulations were replicated 100 times with means and standard deviations shown. Similar plots showing the impact on specific jurisdictions and other incursion scenarios can be found in Appendix 2. Note that due to the large variation in impacts both between and within crop (Figure 1) the proportion crop impact was fixed at 10% in order to explore variability due to incursion location and the size and distribution of different soft-fruit production industries. Thus, the plotted standard deviation reflects uncertainty in dispersal processes rather than damage.

Table 3. Accumulated impacts in dollars (millions) at 3 years following *D. suzukii* establishment within each state jurisdiction, for each local incursion scenario, and commodity category. Simulations were replicated 100 times with means and standard deviations shown. Due to the large variation in impacts both between and within crop (Figure 1) the proportion crop impact was fixed at 10% in order to isolate variability caused by incursion location and the size and distribution of different soft-fruit production industries. Additional incursions and time slices can be found in Appendix 2.

state	*incursion*	*apricots*	*blueberries*	*cherries*	*grapes*	*nectarines*	*peaches*	*plums*	*caneberries*	*strawberries*	*total*
NSW	Coffs Harbour	0.00 (0.00)	3.41 (3.77)	0.03 (0.11)	0.00 (0.00)	0.26 (0.14)	0.16 (0.09)	0.04 (0.02)	0.18 (0.11)	0.09 (0.05)	4.18 (3.93)
NSW	Sydney	0.00 (0.00)	4.68 (3.54)	0.14 (0.22)	0.00 (0.00)	0.50 (0.02)	0.32 (0.01)	0.08 (0.00)	0.41 (0.02)	0.23 (0.01)	6.36 (3.58)
QLD	Brisbane	0.03 (0.02)	2.23 (0.20)	0.00 (0.00)	0.09 (0.07)	0.22 (0.07)	0.24 (0.07)	0.13 (0.07)	1.00 (0.04)	29.33 (1.31)	33.28 (1.60)
QLD	Cairns	0.02 (0.01)	1.88 (0.22)	0.00 (0.00)	0.14 (0.04)	0.12 (0.05)	0.13 (0.06)	0.06 (0.05)	0.83 (0.10)	23.86 (2.99)	27.04 (3.32)
SA	Adelaide	0.02 (0.00)	0.01 (0.00)	4.61 (0.01)	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)	0.06 (0.00)	0.04 (0.00)	6.52 (0.09)	11.28 (0.11)
SA	Port Augusta	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Tas	Devonport	0.01 (0.01)	2.67 (0.10)	4.01 (1.60)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	1.08 (0.29)	5.09 (0.33)	12.88 (2.03)
Tas	Hobart	0.03 (0.01)	0.97 (0.48)	9.30 (0.68)	0.00 (0.00)	0.01 (0.00)	0.03 (0.00)	0.00 (0.00)	1.23 (0.21)	1.53 (0.72)	13.10 (1.56)
Vic	Melbourne	0.05 (0.07)	0.51 (0.04)	2.71 (0.42)	0.00 (0.00)	0.04 (0.03)	0.07 (0.09)	0.09 (0.11)	1.57 (0.10)	10.36 (0.63)	15.40 (1.02)
Vic	Mildura	0.00 (0.01)	0.06 (0.13)	0.26 (0.54)	2.87 (0.00)	0.00 (0.01)	0.00 (0.01)	0.01 (0.01)	0.20 (0.39)	1.37 (2.57)	4.77 (3.62)
WA	Geraldton	0.02 (0.01)	0.05 (0.03)	0.01 (0.01)	0.30 (0.14)	0.87 (0.30)	0.49 (0.17)	0.62 (0.22)	0.01 (0.03)	2.80 (1.39)	5.16 (1.82)
WA	Perth	0.04 (0.00)	0.11 (0.02)	0.02 (0.02)	0.68 (0.07)	1.76 (0.05)	1.00 (0.02)	1.31 (0.09)	0.04 (0.04)	5.97 (0.31)	10.92 (0.39)

Discussion

Australia's significant fruit production industries are increasingly threatened by *D. suzukii* as its rapid global range expansion continues. In this first study to review internationally reported crop loss and quantify impacts to Australian industries based on population growth rates and spread processes, the value of crop losses was estimated at $16.6 – 61.3 million in the first 3 years following simulated incursions into Australian coastal capital cities (assuming a fixed 10% crop loss). These unmitigated impact estimates provide a benchmark for decision making, but it is important to note that realised impacts will also vary considerably depending on grower awareness of the pest, the speed of transition to management strategies, biosecurity responses, and crop vulnerability.

As found in the review of crop loss reports, the most vulnerable fruits (and mean reported crop losses) included raspberries (31%), blackberries (24%), cherries (17%), blueberries (14%), strawberries (8%) and table grapes (7%). Most impacts are predicted to occur in south-eastern Australia, particularly Brisbane and Victoria, due to its substantial strawberry, cherry, and caneberry growing regions. Importantly, impacts did not necessarily scale with the size of the affected industry but also depended on the environmental suitability and isolation of each industry's production regions, highlight the important of considering climatic suitability and spread potential. These same considerations also result in different industries having different vulnerabilities to different incursion scenarios, which may lead to unique biosecurity priorities for each industry.

After compiling international reports of crop losses, most variation in impacts was associated with commodity type and years since establishment. The association with commodity type is likely to reflect intrinsic factors such as permeability of fruit skin (Stewart et al. 2014) or frost susceptibility (Little et al. 2017), while the negative association with years since establishment likely reflects changes in cultural practices, such as harvest schedules, and chemical and biological control strategies in response to the new pest. This finding will help justify a quick transition to best practice management practices to avoid the initial high losses following establishment. While region (as represented by latitude) accounted for a small but significant amount of variation in crop losses, the direction of the relationship was opposite to expectation based on previous models of environmental suitability predicting low latitude locations such as Florida being most suitable (Dos Santos et al. 2017; Ørsted and Ørsted 2019; Maino 2020). Despite these associations, large unexplained variation in crop losses remained (64%). This is due, in part, to substantial reporting error with true proportions of crop lost difficult to define and measure in practice, as evidenced by wide ranges of damage often reported rather than point estimates. Similarly, due to the coarse nature of this study, the covariates selected were also coarse, e.g. years since establishment as a proxy for management rather than the specific management practices implemented.

The large changes in estimated impacts with increasingly model complexity highlight the importance of considering environmental suitability and dispersal processes when forecasting likely impacts of novel pests. While environmental suitability is frequently considered in impact estimates (Kehlenbeck et al. 2012), spread processes are less routinely incorporated due primarily to the large uncertainty and resulting data requirements necessary to model spread. However, due to the increasing predominance of human-mediated dispersal processes in modern biological invasions, a large component of variation in patterns of spread can be captured by environmental suitability and human mediated dispersal (Hudgins et al. 2017; Maino 2020). This supports the notion of more generic and simple models of spreads that can be more routinely incorporated into impact analyses.

Conversely, the predominance of human-assisted spread in modern biological invasions highlights the importance of human mitigation efforts in reducing the rate spread and associated accumulation of impact. Natural rates of spread in *D. suzukii* are approximately 100 m per day (Kirkpatrick et al. 2018; Vacas et al. 2019) while, simultaneously, *D. suzukii* was observed to have spread ~4000 km from California to Florida in the space of one year (Fraimout et al. 2017). Effective quarantine measures are thus likely play a vital role in mitigating impacts.

Mitigation of impacts will also require the rapid transition to management in the event of local establishment to avoid many of the worst impacts. Overseas this has included effective pest identification so that *D. suzukii* are readily distinguished from other common and visually similar drosophilids that do not pose a production threat (Atallah et al. 2014) through the use of trapping (Kirkpatrick et al. 2017). Cultural controls such as optimised harvest schedules and sanitation of crop has also been shown to improve profitability outcomes (Leach et al.

2018). Finally, chemical control has been adopted as a key tool in managing impacts (Van Timmeren and Isaacs 2013) but has resulted in the severe disruption of integrated pest management programs (Van Steenwyk and Bolda 2014). More recently, successful reports of augmentative biological control are emerging, which may offer a means of pest control that is less disruptive to existing management programs (Gonzalez-Cabrera et al. 2019).

If international experience with *D. suzukii* is indicative of the risks posed to Australia's horticultural industry, considerable challenges lay ahead to minimise incursions, establishment, and spread, and ensure producers possess the knowledge to quickly and smoothly transition to management. Simultaneously, Australia is in the fortunate position to be able to utilise the rapidly accumulating scientific knowledge around this pest that would have been unavailable prior to 2008. If Australia utilises overseas experiences, through well-designed quarantine, diagnostics, surveillance and management strategies, the impacts of *D. suzukii* can certainly be mitigated to a large degree.

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Supplementary figures

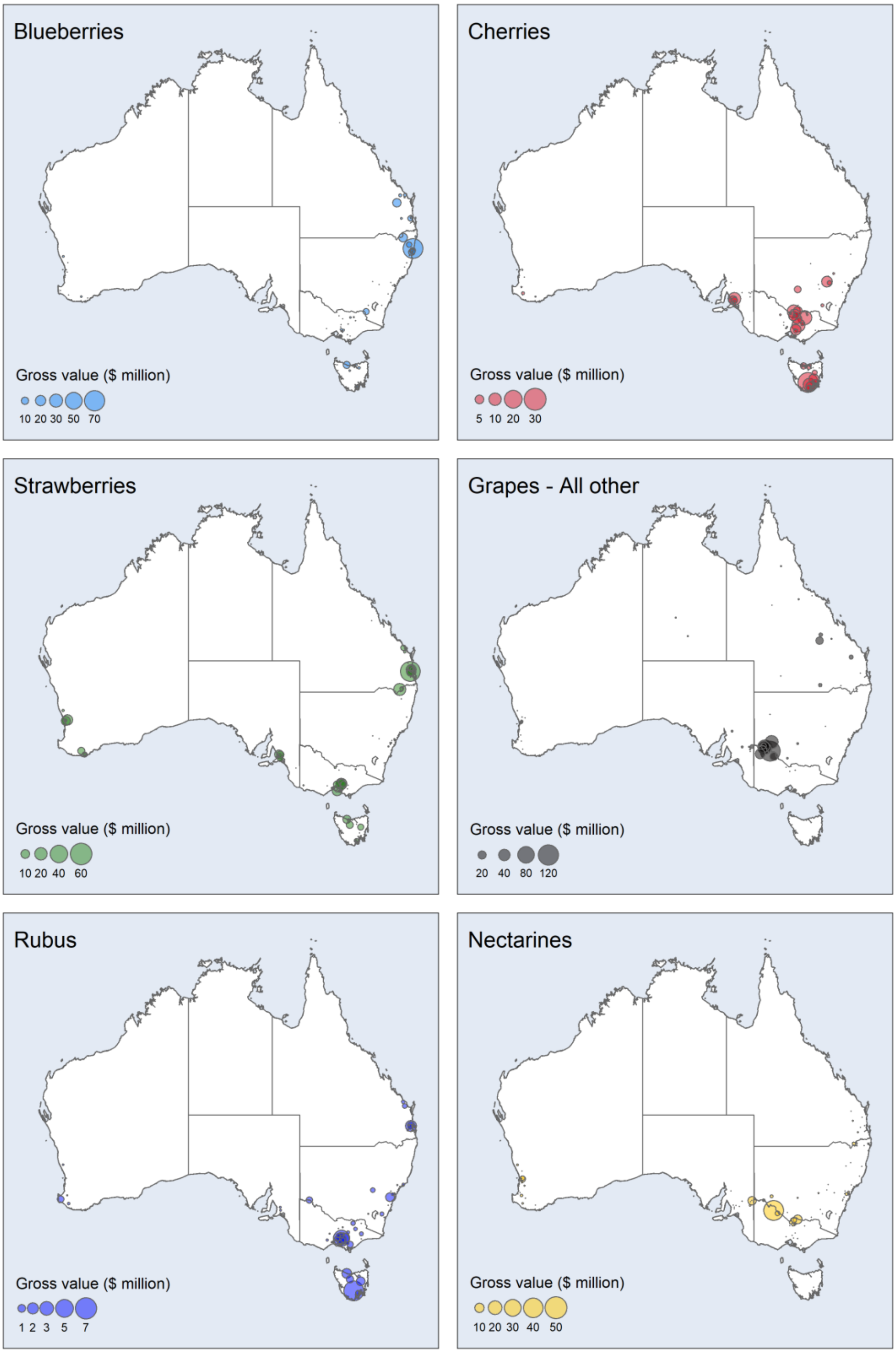

Figure S1. Distribution of the key production regions as shown by the local value ($ million) of commodity production based on ABS agricultural census data collected for 2015-16.

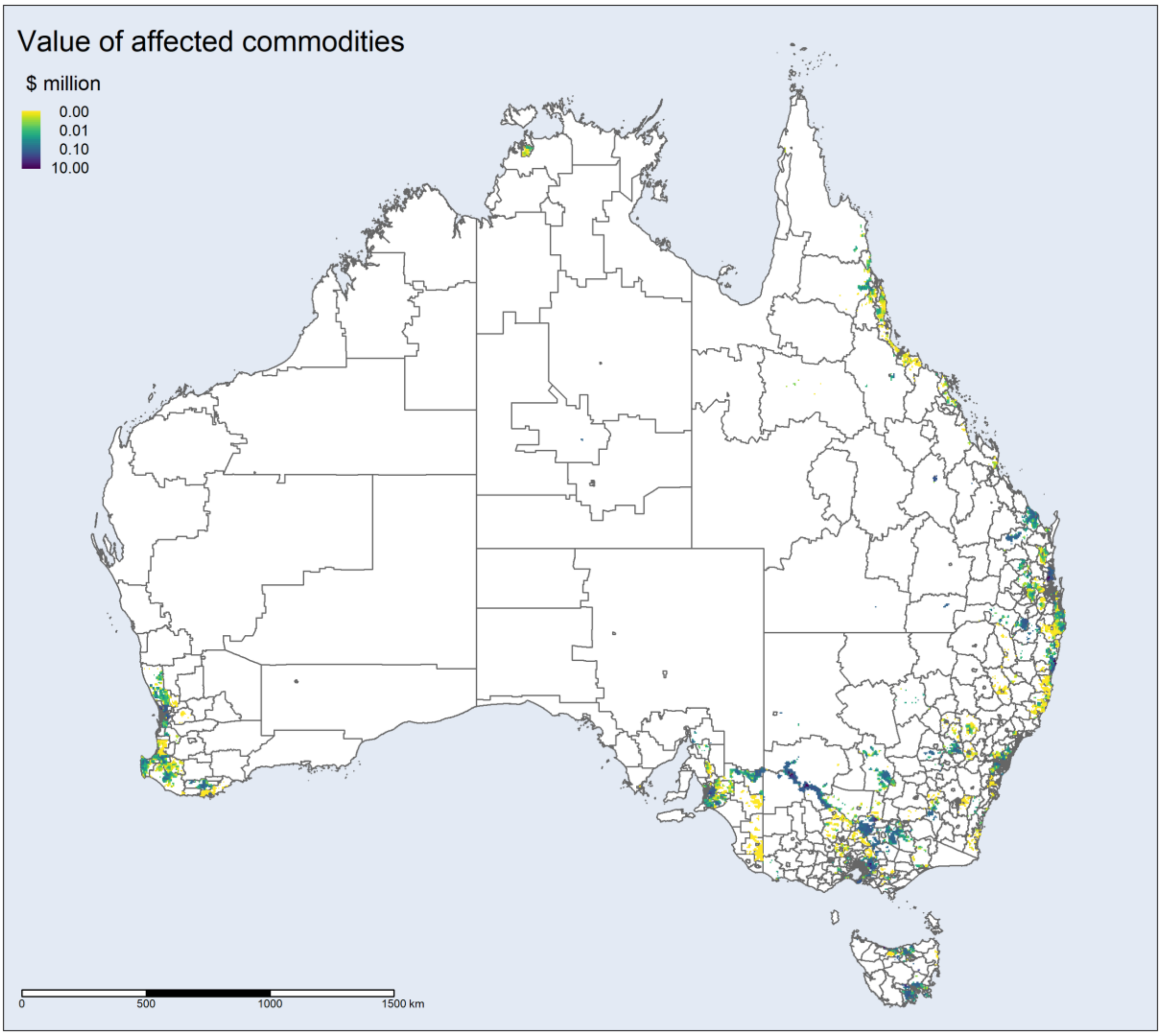

Figure S2. Gridded estimate of commodity production in terms of local values affected by *D. suzukii* for each 5km grid cell with ABS Statistical Area Division 2 regions overlaid.

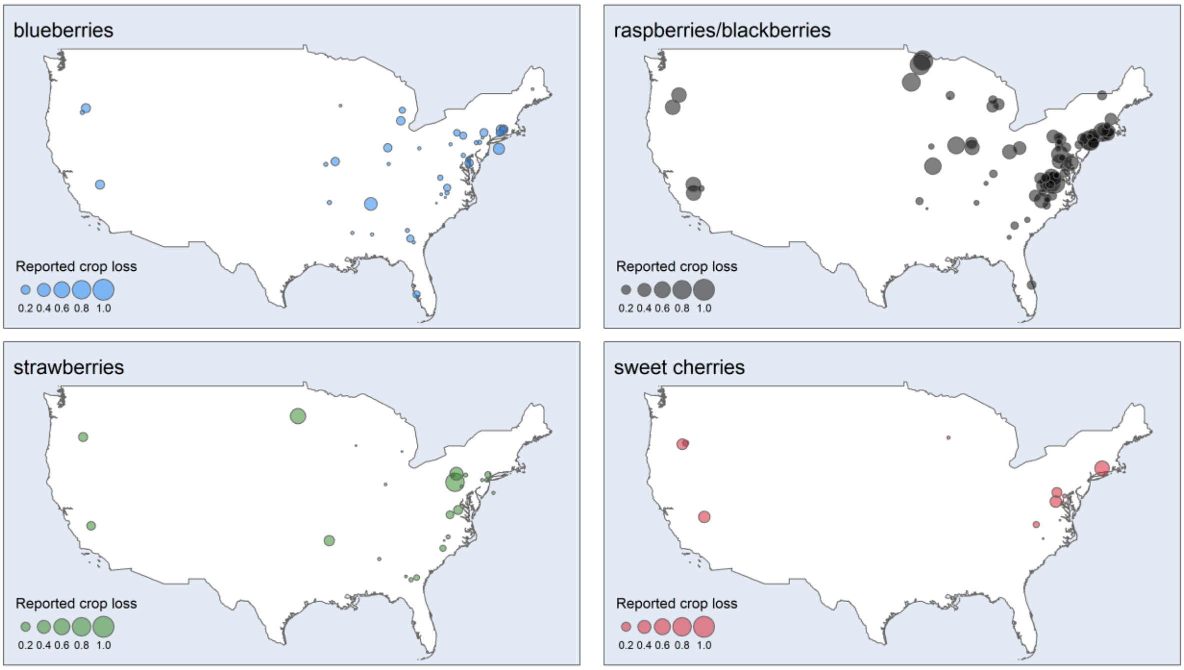

Figure S3. Spatial distribution of reported proportion crop losses in the United States for four important commodity groups. Increasing circle sizes denotes the reported amount of crop loss. Some locations are inferred from state level locational information and are thus only approximate. Points are slightly offset so that multiple reports can be viewed.

Appendix 1 – Literature review of reported crop losses to *D. suzukii*

Plant name	Common name	Impact estimate	Location	Notes	Source
Vitis	table grapes	0.1	Connecticut, United States	500 acres Crop value not reported	eFly working group, 2012
Vitis	table grapes	0	Michigan, United States	12,600 acres Value not reported Juice grapes	eFly working group, 2012
Vitis	table grapes	0.02	New York, United States	37,000 acres $68,404,000 grown $1,368,000 estimated crop loss	eFly working group, 2012
Vitis	table grapes	0	North Carolina, United States	1800 acres Value not reported Muscadine and bunch grapes have an estimated $1,280,000,000 economic impact	eFly working group, 2012
Vitis	table grapes	0.005	Pennsylvania, United States	14,000 acres $21,000,000 grown $0 - $210,000 estimated crop loss Mostly Concord	eFly working group, 2012
Vitis	table grapes	0	Alabama, United States	Number of Responses: 4; Estimated crop value: $2,649,219*; Estimated crop value lost: $0; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Vitis	table grapes	0	Georgia, United States	Number of Responses: 6; Estimated crop value: $5,624,000; Estimated crop value lost: $0; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Vitis	table grapes	0.02	Kentucky, United States	Number of Responses: 12; Estimated crop value: $3,195,398*; Estimated crop value lost: $63,908; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Vitis	table grapes	0.04	Maryland, United States	Number of Responses: 7; Estimated crop value: $3,476,144*; Estimated crop value lost: $139,046; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014

Vitis	table grapes	0.02	North Carolina, United States	Number of Responses: 16; Estimated crop value: $4,469,000; Estimated crop value lost: $89,380; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Vitis	table grapes	0.05	Pennsylvania, United States	Number of Responses: 4; Estimated crop value: $20,555,000; Estimated crop value lost: $1,027,750; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Vitis	table grapes	0.15	Tennessee, United States	Number of Responses: 3; Estimated crop value: $4,619,545*; Estimated crop value lost: $692,932; For all US Grapes in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Vitis	table grapes	0.02	Arkansas, United States	Number of Responses: 5; Estimated crop value: $4,011,984; Estimated crop value lost: $80,240; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.03	Connecticut, United States	Number of Responses: 6; Estimated crop value: $2,986,699; Estimated crop value lost: $89,601; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.07	Georgia, United States	Number of Responses: 3; Estimated crop value: $10,815,640; Estimated crop value lost: $757,095; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.2	Indiana, United States	Number of Responses: 12; Estimated crop value: $3,438,047; Estimated crop value lost: $687,609; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.2	Maryland, United States	Number of Responses: 4; Estimated crop value: $3,794,668; Estimated crop value lost: $758,934; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.01	North Carolina, United States	Number of Responses: 23; Estimated crop value: $933,000; Estimated crop value lost: $9,330; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Vitis	table grapes	0.04	New York, United States	Number of Responses: 8; Estimated crop value: $5,070,000; Estimated crop value lost: $160,240; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.05	Oregon, United States	Number of Responses: 6; Estimated crop value: $118,320,000; Estimated crop value lost: $5,916,000; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.15	Virginia, United States	Number of Responses: 27; Estimated crop value: $12,784,000; Estimated crop value lost: $1,917,600; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	table grapes	0.03	Wisconsin, United States	Number of Responses: 11; Estimated crop value: $4,552,487; Estimated crop value lost: $136,575; For all US Grapes in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vitis	wine grapes	0	Michigan, United States	2000 Value not reported Wine grapes	eFly working group, 2012
Rubus	blackberries	0.5	California, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Rubus	blackberries	0.5	Oregon, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Rubus	blackberries	0.5	Washington, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Rubus	blackberries	0.15	Trentino, Italy	Mean of 11 and 19% for raspberries and blackberries respectively in 2011-2012 Trento, Italy.	De Ros et al., 2015
Rubus	blackberries	0.2	Virginia, United States	12 acres Not reported 20% crop loss or $8500 per acre = $102,000 10 additional insecticide treatments	eFly working group, 2012
Rubus	blackberries	1	Virginia, United States	0.5 acres Value not reported 100% crop loss in 2012; 50% crop loss in 2011 4 additional insecticide applications ($5/application); no insecticide applications before 2012	eFly working group, 2012

Rubus	blackberries	0.5	Virginia, United States	0.5 acres Value not reported 100% crop loss in 2012; 50% crop loss in 2011 4 additional insecticide applications ($5/application); no insecticide applications before 2012	eFly working group, 2012
Rubus	blackberries	0	Arkansas, United States	400 acres (blackberries) 20 acres (raspberries) D. suzukii detected in 2012	eFly working group, 2012
Rubus	blackberries	0.3	Michigan, United States	500 acres (blackberries) 500 acres (raspberries) $2,000,000 grown $600,000 crop loss $58/acre increase in production costs (blackberries); $116/acre increase in production costs (raspberries)	eFly working group, 2012
Rubus	blackberries	0.8	New York, United States	500 acres $3,746,000 grown $2,997,000 crop loss	eFly working group, 2012
Rubus	blackberries	0.15	North Carolina, United States	450 acres (blackberries) 50 acres (raspberries) $14,300,000^ grown $2,145,000 crop loss Estimated $163/acre increase in production costs; Nearly all commercial growers have lost some crop to D. suzukii	eFly working group, 2012
Rubus	blackberries	0.1	Pennsylvania, United States	120 acres (blackberries) 300 acres (raspberries) $2,000,000 $200,000 crop loss Majority of losses in late season blackberries and fall raspberries	eFly working group, 2012
Rubus	blackberries	0	Alabama, United States	Number of Responses: 6; Estimated crop value: $2,623,700*; Estimated crop value lost: $0; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.4	Connecticut, United States	Number of Responses: 4; Estimated crop value: $365,325*; Estimated crop value lost: $146,130; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014

Rubus	blackberries	0.18	Florida, United States	Number of Responses: 2; Estimated crop value: $5,081,344*; Estimated crop value lost: $914,642; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.14	Georgia, United States	Number of Responses: 8; Estimated crop value: $9,465,249*; Estimated crop value lost: $1,325,134; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.14	Kentucky, United States	Number of Responses: 11; Estimated crop value: $4,068,397*; Estimated crop value lost: $569,576; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.2	Maryland, United States	Number of Responses: 10; Estimated crop value: $747,257*; Estimated crop value lost: $149,451; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0	Missouri, United States	Number of Responses: 6; Estimated crop value: $4,300,879*; Estimated crop value lost: $0; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.1	North Carolina, United States	Number of Responses: 18; Estimated crop value: $6,725,309*; Estimated crop value lost: $672,530; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0	New Jersey, United States	Number of Responses: 2; Estimated crop value: $1,461,301*; Estimated crop value lost: $0; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.23	Pennsylvania, United States	Number of Responses: 8; Estimated crop value: $2,441,038*; Estimated crop value lost: $561,439; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.07	South Carolina, United States	Number of Responses: 3; Estimated crop value: $2,723,335*; Estimated crop value lost: $190,633; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014

Rubus	blackberries	0.06	Tennessee, United States	Number of Responses: 3; Estimated crop value: $5,131,161*; Estimated crop value lost: $307,870; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.11	Virginia, United States	Number of Responses: 9; Estimated crop value: $4,466,933*; Estimated crop value lost: $491,363; For all US Blackberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	blackberries	0.13	Arkansas, United States	Number of Responses: 20; Estimated crop value: $8,831,616; Estimated crop value lost: $1,148,110; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.35	Connecticut, United States	Number of Responses: 4; Estimated crop value: $404,782; Estimated crop value lost: $141,674; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.04	Georgia, United States	Number of Responses: 11; Estimated crop value: $10,487,544; Estimated crop value lost: $419,502; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.67	Illinois, United States	Number of Responses: 3; Estimated crop value: $2,171,106; Estimated crop value lost: $1,454,641; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.34	Indiana, United States	Number of Responses: 7; Estimated crop value: $2,820,000; Estimated crop value lost: $450,412; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.13	Maryland, United States	Number of Responses: 6; Estimated crop value: $827,964; Estimated crop value lost: $107,635; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.32	North Carolina, United States	Number of Responses: 20; Estimated crop value: $7,451,676; Estimated crop value lost: $2,384,536; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Rubus	blackberries	0.1	New York, United States	Number of Responses: 13; Estimated crop value: $4,084,622; Estimated crop value lost: $408,462; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.46	Ohio, United States	Number of Responses: 4; Estimated crop value: $6,476,518; Estimated crop value lost: $2,979,198; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.23	Pennsylvania, United States	Number of Responses: 6; Estimated crop value: $2,704,682; Estimated crop value lost: $622,077; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.17	Virginia, United States	Number of Responses: 13; Estimated crop value: $4,949,385; Estimated crop value lost: $841,395; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	0.02	Wisconsin, United States	Number of Responses: 3; Estimated crop value: $883,162; Estimated crop value lost: $17,663; For all US Blackberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	blackberries	1	Trentino, Italy	Severe infestations occurred in the middle of summer (July/August) on the early ripening cultivated blackberries of cv. Lochness. Sant'Orsola local soft fruits growers association (APASO) reported a 30-40% loss of production on this crop. In September and October, from 60 to 100% of red raspberries fruits sampled at the right commercial ripening stage (pink/red colour) in some untreated plantations, were infested by eggs. Eggs were found till the beginning of November. One of the main reasons for this high susceptibility was the long harvest period, that unfortunately occured during the peaks of D. suzukii adult flight in Trentino.	Grassi et al., 2011
Rubus	blackberries	0.9	Grand Rapids, MN, United States	No pest control, natural infestation of field plots harvested at one point in 2014 and multiple points in 2015.	Sward et al., 2016
Vaccinium	blueberries	0.2	California, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010

Vaccinium	blueberries	0.2	Oregon, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Vaccinium	blueberries	0.17	Washington, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Vaccinium	blueberries	0.42	Trentino, Italy	2011-2012 Trento, Italy.	De Ros et al., 2015
Vaccinium	blueberries	0.125	Pennsylvania, United States	900 acres, $4,450,000 grown, 10-15% estimated loss, $400,000 - $450,000 crop loss Fruit affected from mid-season onward; Early varieties largely escaped damage	eFly working group, 2012
Vaccinium	blueberries	0.02	Maine, United States	Wild blueberries, est. 60,000 acres $69,075,000* 2% $1,381,500 crop loss 2 million lb of fruit; Last 2 weeks of harvest the “wash water ran purple”, so actual losses might be higher	eFly working group, 2012
Vaccinium	blueberries	0.01	North Carolina, United States	1296 acres Not reported 1% or less Data for single county, 5-6 additional insecticide applications of malathion followed by pyrtheroid; $46,656-69,984 increase in pesticide costs across county	eFly working group, 2012
Vaccinium	blueberries	0	Arkansas	D. suzukii detected in 2012 - same year of study	eFly working group, 2012
Vaccinium	blueberries	0.2	Connecticut, United States	410 acres, $6,817,000 grown 20% rough estimated loss $1,363,400 crop loss	eFly working group, 2012
Vaccinium	blueberries	0.125	Georgia, United Stated	15,000 acres, $94,130,000 grown, 10-15% estimated loss, $9,413,000 - $14,119,500 crop loss, Estimated $3,000,000 increase in production costs	eFly working group, 2012
Vaccinium	blueberries	0.125	Florida, United States	4800 acres, $78,000,000 damage 10-15% estimated loss $7,800,000 - $11,700,000 crop loss	eFly working group, 2012

Vaccinium	blueberries	0.1	Michigan, United States	22,000 acres, $120,000,000 grown, $12,000,000 crop loss $290 production cost increase/acre	eFly working group, 2012
Vaccinium	blueberries	0.05	New Jersey, United States	7700 acres, $87,800,000 grown, 5% estimated loss $4,400,000 crop loss Prehavest samples 40-50% samples positives, less in packed product; about 33% infestation in frozen fruit based on limited surveys	eFly working group, 2012
Vaccinium	blueberries	0.3	New York, United States	900 acres, $4,521,000 grown, 30% estimated loss, $1,356,000 crop loss	eFly working group, 2012
Vaccinium	blueberries	0.015	North Carolina, United States	6600 acres, $66,000,000 grown, 1-2% estimated losses, $660,000 - $1,320,000 crop loss Insecticide applications increased estimated 10-50%; $36-54 increase per acre in pesticide costs alone	eFly working group, 2012
Vaccinium	blueberries	0.03	Alabama, United States	Number of Responses: 8; Estimated crop value: $1,484,000; Estimated crop value lost: $445,20; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.13	Connecticut, United States	Number of Responses: 7; Estimated crop value: $4,336,675*; Estimated crop value lost: $563,768; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0	Florida, United States	Number of Responses: 2; Estimated crop value: $62,073,000; Estimated crop value lost: $0; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.04	Georgia, United States	Number of Responses: 17; Estimated crop value: $94,130,000; Estimated crop value lost: $3,765,200; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014

Vaccinium	blueberries	0.03	Kentucky, United States	Number of Responses: 10; Estimated crop value: $3,593,819*; Estimated crop value lost: $107,815; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.05	Maryland, United States	Number of Responses: 10; Estimated crop value: $1,375,288*; Estimated crop value lost: $68,764; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.04	Missouri, United States	Number of Responses: 8; Estimated crop value: $1,947,488*; Estimated crop value lost: $77,900; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.03	Mississippi, United States	Number of Responses: 15; Estimated crop value: $15,550,000; Estimated crop value lost: $466,500; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.02	North Carolina, United States	Number of Responses: 19; Estimated crop value: $71,000,000; Estimated crop value lost: $1,420,000; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.05	New Jersey, United States	Number of Responses: 15; Estimated crop value: $80,805,000; Estimated crop value lost: $4,040,250; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.02	New York, United States	Number of Responses: 9; Estimated crop value: $3,893,000; Estimated crop value lost: $77,860; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.03	Pennsylvania, United States	Number of Responses: 12; Estimated crop value: $10,369,874*; Estimated crop value lost: $311,096; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.02	South Carolina, United States	Number of Responses: 5; Estimated crop value: $5,691,886*; Estimated crop value lost: $113,838; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014

Vaccinium	blueberries	0.39	Tennessee, United States	Number of Responses: 3; Estimated crop value: $3,573,742*; Estimated crop value lost: $1,393,759; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.13	Virginia, United States	Number of Responses: 4; Estimated crop value: $4,246,373*; Estimated crop value lost: $552,028; For all US Blueberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Vaccinium	blueberries	0.05	Arkansas, United States	Number of Responses: 22; Estimated crop value: $619,000; Estimated crop value lost: $30,950; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.14	Connecticut, United States	Number of Responses: 8; Estimated crop value: $4,410,158; Estimated crop value lost: $617,422; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.03	Georgia, United States	Number of Responses: 85; Estimated crop value: $109,800,000; Estimated crop value lost: $3,294,000; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.17	Indiana, United States	Number of Responses: 6; Estimated crop value: $2,780,000; Estimated crop value lost: $472,600; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.02	Massachusetts, United States	Number of Responses: 3; Estimated crop value: $7,891,325; Estimated crop value lost: $157,827; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.06	Maryland, United States	Number of Responses: 5; Estimated crop value: $1,398,592; Estimated crop value lost: $83,916; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.19	Michigan, United States	Number of Responses: 14; Estimated crop value: $114,320,000; Estimated crop value lost: $21,720,800; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Vaccinium	blueberries	0.17	Missouri, United States	Number of Responses: 3; Estimated crop value: $1,980,488; Estimated crop value lost: $336,683; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.05	North Carolina, United States	Number of Responses: 41; Estimated crop value: $72,181,000; Estimated crop value lost: $3,609,050; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.02	New Jersey, United States	Number of Responses: 12; Estimated crop value: $79,181,000; Estimated crop value lost: $1,589,260; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.16	New York, United States	Number of Responses: 24; Estimated crop value: $4,208,000; Estimated crop value lost: $673,280; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.03	Ohio, United States	Number of Responses: 5; Estimated crop value: $3,889,515; Estimated crop value lost: $116,685; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.05	Oregon, United States	Number of Responses: 6; Estimated crop value: $106,692,000; Estimated crop value lost: $5,334,600; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.11	Pennsylvania, United States	Number of Responses: 8; Estimated crop value: $10,545,592; Estimated crop value lost: $1,160,015; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.24	Rhode Island, United States	Number of Responses: 6; Estimated crop value: $1,398,592; Estimated crop value lost: $335,662; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	0.07	Virginia, United States	Number of Responses: 19; Estimated crop value: $4,318,280; Estimated crop value lost: $302,280; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Vaccinium	blueberries	0.02	Wisconsin, United States	Number of Responses: 6; Estimated crop value: $3,909,932; Estimated crop value lost: $78,199; For all US Blueberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Vaccinium	blueberries	1	Trentino, Italy	Highbush blueberry was one of the most damaged crop. In some sites (e.g Samone, in Valsugana South), 90-100% of the fruits were infested at the end of harvest. APASO reported a 30-40% loss of production due to D. suzukii infestation. Additional severe losses occurred after a long fruit storage period, since during this time undetected eggs and very young larvae continued to develop inside the pulp. On blueberry, eggs were frequently recorded also on unripe fruits. Besides a very long harvest period, the high number of ripe fruits that fall on the ground or remain on the bushes during the harvest represented one of the main reasons for this high susceptibility	Grassi et al., 2011
Ficus carica	common fig	NA	Trentino, Italy	Many eggs had been counted on figs collected from a tree in Vigalzano, Pergine (Valsugana North).	Grassi et al., 2011
Ribes	currants	0	Trentino, Italy	No damages were recorded on red currant.	Grassi et al., 2011
Psidium cattleianu	guava	0.74	Veracruz, Mexico.	To determine whether both drosophilids were infesting guava, a previously unreported host, samples were taken from fruits on trees and fallen fruits on the ground in Veracruz, Mexico.	Lasa et al., 2017
Actinidia	kiwi	0.01	Oregon, United States	Information lacking so 1% damage assumed. D. suzukii reported in kiwis (Walsh 2011), and in traps adjacent to kiwi crops (Stewart 2015) but no damage reported to date. Possibly skin thickness and hair will be a deterant to D. suzukii (Stewart 2018). Kiwifruit: there is no evidence that gold or green kiwifruit (Actinidia chinensis and A. deliciosa respectively) are hosts for D. suzukii. Hardy kiwis (kiwiberries or A. arguta) are confirmed hosts but there are no reports of significant impacts on this crop. Impacts on the kiwifruit industry would not be	MPI, 2012

				expected to be significant.	
Diospyros kaki	persimmon	0.01	Japan	Damage assumed very low at 1%. Extracted from Barbour 2013 Final PRA report on D. suzukii. Although listed as a host (ODA 2009), adults have only emerged from fruit that was either split, damaged, dropped or cut (Kanzawa 1939).	Kanzawa, 1939
Rubus	raspberries	0.5	California, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Rubus	raspberries	0.5	Oregon, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Rubus	raspberries	0.5	Washington, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Rubus	raspberries	0.15	Trentino, Italy	Mean of 11 and 19% for raspberries and blackberries respectively in 2011-2012 Trento, Italy.	De Ros et al., 2015
Rubus	raspberries	0.2	Virginia, United States	12 acres Not reported 20% crop loss or $8500 per acre = $102,000 10 additional insecticide treatments	eFly working group, 2012
Rubus	raspberries	1	Virginia, United States	0.5 acres Value not reported 100% crop loss in 2012; 50% crop loss in 2011 4 additional insecticide applications ($5/application); no insecticide applications before 2012	eFly working group, 2012
Rubus	raspberries	0.5	Virginia, United States	0.5 acres Value not reported 100% crop loss in 2012; 50% crop loss in 2011 4 additional insecticide applications ($5/application); no insecticide applications before 2012	eFly working group, 2012

Rubus	raspberries	0.3	Virginia, United States	Raspberries 0.8 Not reported 90% crop loss in 2012 (estimated at $4000); 30% crop loss in 2011 Organic practices, 4 insecticide applications ($111 total); no insecticide applied before 2012	eFly working group, 2012
Rubus	raspberries	0.125	Connecticut, United States	Raspberries 5 acres $70,140 10-15% (with insecticides); 80% (without insecticides, 2011) 7 additional insecticide applications in 2012 ($10,125 in additional cost for pesticides and labor)	eFly working group, 2012
Rubus	raspberries	0.8	Connecticut, United States	Raspberries 5 acres $70,140 10-15% (with insecticides); 80% (without insecticides, 2011) 7 additional insecticide applications in 2012 ($10,125 in additional cost for pesticides and labor)	eFly working group, 2012
Rubus	raspberries	0	Arkansas, United States	400 acres (blackberries) 20 acres (raspberries) D. suzukii detected in 2012	eFly working group, 2012
Rubus	raspberries	0.4	Connecticut, United States	129 acres (raspberries) $1,806,000 grown $722,400 crop loss	eFly working group, 2012
Rubus	raspberries	0.3	Michigan, United States	500 acres (blackberries) 500 acres (raspberries) $2,000,000 grown $600,000 crop loss $58/acre increase in production costs (blackberries); $116/acre increase in production costs (raspberries)	eFly working group, 2012
Rubus	raspberries	0.8	New York, United States	500 acres $3,746,000 grown $2,997,000 crop loss	eFly working group, 2012

Rubus	raspberries	0.15	North Carolina, United States	450 acres (blackberries) 50 acres (raspberries) $14,300,000^ grown $2,145,000 crop loss Estimated $163/acre increase in production costs; Nearly all commercial growers have lost some crop to D. suzukii	eFly working group, 2012
Rubus	raspberries	0.1	Pennsylvania, United States	120 acres (blackberries) 300 acres (raspberries) $2,000,000 $200,000 crop loss Majority of losses in late season blackberries and fall raspberries	eFly working group, 2012
Rubus	raspberries	0.31	Connecticut, United States	Number of Responses: 7; Estimated crop value: $1,110,690*; Estimated crop value lost: $344,314; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.04	Kentucky, United States	Number of Responses: 6; Estimated crop value: $555,345*; Estimated crop value lost: $22,214; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.03	Maryland, United States	Number of Responses: 10; Estimated crop value: $774,900*; Estimated crop value lost: $23,247; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.07	Missouri, United States	Number of Responses: 3; Estimated crop value: $400,365*; Estimated crop value lost: $28,026; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.19	North Carolina, United States	Number of Responses: 7; Estimated crop value: $891,135*; Estimated crop value lost: $169,316; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.17	New Jersey, United States	Number of Responses: 2; Estimated crop value: $1,097,775*; Estimated crop value lost: $186,622; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014

Rubus	raspberries	0.31	New York, United States	Number of Responses: 9; Estimated crop value: $8,846,775*; Estimated crop value lost: $2,742,500; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.15	Pennsylvania, United States	Number of Responses: 12; Estimated crop value: $3,616,200*; Estimated crop value lost: $542,430; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.14	Virginia, United States	Number of Responses: 7; Estimated crop value: $1,743,525*; Estimated crop value lost: $244,094; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.2	Vermont, United States	Number of Responses: 2; Estimated crop value: $1,420,650*; Estimated crop value lost: $284,130; For all US Raspberries in 2013: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2014
Rubus	raspberries	0.013	Arkansas, United States	Number of Responses: 5; Estimated crop value: $543,767; Estimated crop value lost: $7,069; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.38	Connecticut, United States	Number of Responses: 7; Estimated crop value: $1,798,613; Estimated crop value lost: $683,473; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.48	Indiana, United States	Number of Responses: 9; Estimated crop value: $1,380,331; Estimated crop value lost: $662,559; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.63	Maryland, United States	Number of Responses: 5; Estimated crop value: $1,254,846; Estimated crop value lost: $790,553; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.17	Michigan, United States	Number of Responses: 3; Estimated crop value: $12,318,405; Estimated crop value lost: $2,094,129; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Rubus	raspberries	0.74	Minnesota, United States	Number of Responses: 4; Estimated crop value: $1,181,793; Estimated crop value lost: $874,527; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.63	Missouri, United States	Number of Responses: 3; Estimated crop value: $648,337; Estimated crop value lost: $408,452; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.48	North Carolina, United States	Number of Responses: 12; Estimated crop value: $1,443,073; Estimated crop value lost: $692,675; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0	New Jersey, United States	Number of Responses: 5; Estimated crop value: $1,777,699; Estimated crop value lost: $0; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.3	New York, United States	Number of Responses: 23; Estimated crop value: $14,326,159; Estimated crop value lost: $4,297,848; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.38	Ohio, United States	Number of Responses: 3; Estimated crop value: $8,386,554; Estimated crop value lost: $3,186,891; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.38	Pennsylvania, United States	Number of Responses: 9; Estimated crop value: $5,855,948; Estimated crop value lost: $2,225,260; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.36	Virginia, United States	Number of Responses: 12; Estimated crop value: $2,300,551; Estimated crop value lost: $828,198; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Rubus	raspberries	0.16	Wisconsin, United States	Number of Responses: 12; Estimated crop value: $5,249,439; Estimated crop value lost: $839,910; For all US Raspberries in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Rubus	raspberries	0.1	California, United States	Analyzing the 40 fruit samples collected from these fields resulted in estimated yield loss observations for raspberries producers employing standard management practices at the time. D. suzukii-induced yield losses for conventional producers in the study were estimated to be approximately 10% of production in 2011 and less than 1%in 2012.2	Farnsworth et al., 2017
Rubus	raspberries	1	Trentino, Italy	Severe infestations occurred in the middle of summer (July/August) on the early ripening cultivated blackberries of cv. Lochness. Sant'Orsola local soft fruits growers association (APASO) reported a 30-40% loss of production on this crop. In September and October, from 60 to 100% of red raspberries fruits sampled at the right commercial ripening stage (pink/red colour) in some untreated plantations, were infested by eggs. Eggs were found till the beginning of November. One of the main reasons for this high susceptibility was the long harvest period, that unfortunately occured during the peaks of D. suzukii adult flight in Trentino.	Grassi et al., 2011
Rubus	raspberries	0.9	Grand Rapids, MN, United States	No pest control, natural infestation of field plots harvested at one point in 2014 and multiple points in 2015.	Sward et al., 2016
Fragaria	strawberries	0.2	Oregon, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Fragaria	strawberries	0.2	Washington, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Fragaria	strawberries	0.18	California, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Fragaria	strawberries	0	Florida, United States	9000 acres $360,000,000 grown	eFly working group, 2012
Fragaria	strawberries	0.05	Georgia, United States	288 acres $4,900,000 grown $245,000 crop loss	eFly working group, 2012
Fragaria	strawberries	0.01	Michigan, United States	800 $4,800,000 grown $96,000 crop loss	eFly working group, 2012
Fragaria	strawberries	0.1	New York, United States	1400 Acres $6,895,000 $702,000 crop loss	eFly working group, 2012

Fragaria	strawberries	0	North Carolina, United States	1800 acres $24,300,000 No crop loss reported to date	eFly working group, 2012
Fragaria	strawberries	0.8	Pennsylvania, United States	1000 acres $8,500,000 grown 0% on June-bearing varieties, up to 80% of fall harvest on day-neutrals $30,000 crop loss	eFly working group, 2012
Fragaria	strawberries	0.1	South Carolina, United States	550 acres $10,750,000 250 acres infested with an estimated 10% loss $500,000 estimated crop loss, including increased production costs	eFly working group, 2012
Fragaria	strawberries	0.4	Pennsylvania, United States	1.5 acres Not reported 40% Day neutral strawberries	eFly working group, 2012
Fragaria	strawberries	0	Alabama, United States	Number of Responses: 3; Estimated crop value: $2,109,584*; Estimated crop value lost: $0; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0.08	Georgia, United States	Number of Responses: 5; Estimated crop value: $1,869,252*; Estimated crop value lost: $149,540; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0	Kentucky, United States	Number of Responses: 5; Estimated crop value: $2,763,823*; Estimated crop value lost: $0; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0.03	Maryland, United States	Number of Responses: 11; Estimated crop value: $2,937,396*; Estimated crop value lost: $88,122; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0.04	North Carolina, United States	Number of Responses: 8; Estimated crop value: $29,435,000; Estimated crop value lost: $1,177,400; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014

Fragaria	strawberries	0.04	New York, United States	Number of Responses: 9; Estimated crop value: $6,880,000; Estimated crop value lost: $275,200; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0.04	Pennsylvania, United States	Number of Responses: 9; Estimated crop value: $8,480,000; Estimated crop value lost: $339,200; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0	Tennessee, United States	Number of Responses: 3; Estimated crop value: $3,818,614*; Estimated crop value lost: $0; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0.15	Virginia, United States	Number of Responses: 6; Estimated crop value: $3,872,022*; Estimated crop value lost: $580,803; For all US strawberries in 2013: Minimum observed loss: 0; Maximum observed loss: 0.5;	eFly working group, 2014
Fragaria	strawberries	0.03	Alabama, United States	Number of Responses: 3; Estimated crop value: $2,052,764; Estimated crop value lost: $61,583; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.26	Arkansas, United States	Number of Responses: 8; Estimated crop value: $818,507; Estimated crop value lost: $212,812; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0	Connecticut, United States	Number of Responses: 6; Estimated crop value: $3,676,787; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.02	Georgia, United States	Number of Responses: 10; Estimated crop value: $1,818,905; Estimated crop value lost: $36,378; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0	Illinois, United States	Number of Responses: 3; Estimated crop value: $4,118,521; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015

Fragaria	strawberries	0.02	Indiana, United States	Number of Responses: 7; Estimated crop value: $3,702,771; Estimated crop value lost: $74,055; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0	Maryland, United States	Number of Responses: 5; Estimated crop value: $2,858,279; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.55	Minnesota, United States	Number of Responses: 4; Estimated crop value: $7,730,346; Estimated crop value lost: $4,251,690; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0	Missouri, United States	Number of Responses: 3; Estimated crop value: $2,546,467; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.01	North Carolina, United States	Number of Responses: 16; Estimated crop value: $23,490,000; Estimated crop value lost: $234,080; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.03	New Jersey, United States	Number of Responses: 6; Estimated crop value: $3,650,802; Estimated crop value lost: $109,524; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.03	New York, United States	Number of Responses: 21; Estimated crop value: $6,880,000; Estimated crop value lost: $225,600; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0	Ohio, United States	Number of Responses: 3; Estimated crop value: $4,200,000; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.04	Pennsylvania, United States	Number of Responses: 4; Estimated crop value: $6,888,000; Estimated crop value lost: $211,200; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015

Fragaria	strawberries	0	South Carolina, United States	Number of Responses: 3; Estimated crop value: $5,794,512; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0	Virginia, United States	Number of Responses: 9; Estimated crop value: $3,767,732; Estimated crop value lost: $0; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.01	Wisconsin, United States	Number of Responses: 15; Estimated crop value: $5,738,000; Estimated crop value lost: $64,350; For all US strawberries in 2014: Minimum observed loss: 0; Maximum observed loss: 0.55;	eFly working group, 2015
Fragaria	strawberries	0.03	Trentino, Italy	The damage on strawberries was negligible (2-3%) until the end of August. Probably, the frequent use of insecticides on this crop during the summer for the control of other important pests (e.g thrips, Lygus spp., Anthonomus rubi) contributed to limit D. suzukii attacks. But a considerable damage (60-80%) was recorded in September on the last harvested fruits of late ripening strawberries (in Tesino and Vanoi sites), when the insecticides pressure was reduced.	Grassi et al., 2011
Malus domestica	apple	0	Japan	The researchers advised that apple and pear were mistakenly listed as hosts in the pest alerts on the basis of the English translation of an abstract of a paper written in Japanese, containing original research on Drosophila suzukii. In the main body of Kanzawa (1939), it is clarified that only damaged or cut apples and pears had been observed to host Drosophila suzukii.	DAFF, 2013
Prunus domestica	plum	0.2	Spain	Extracted from Barbour 2013 Final PRA report on D. suzukii. "In Spain, damage in cherry (100%), peaches (10-40%), plums (20%) and strawberries (20%) has also been reported (Escudero et al. 2011; Sarto and Sorribas 2011)."	Escudero et al., 2011
Prunus domestica	plum	NA	NA	NA	Sarto and Sorribas, 2011

Prunus armeniaca	apricot	0.35	Trentino, Italy	In August, from 20 to 50% of apricots sampled from orchards located in the same cherry production districts, resulted infested by D. suzukii eggs detected also on hard and unripe (green/orange) fruits.	Grassi et al., 2011
Prunus avium	sweet cherries	0.32	California, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Prunus avium	sweet cherries	0.28	Oregon, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Prunus avium	sweet cherries	0.32	Washington, United States	Yield loss estimates from 2009 observations	Bolda et al., 2010
Prunus avium	sweet cherries	0.5	Connecticut, United States	12 acres $300,000 grown $150,000 crop loss	eFly working group, 2012
Prunus avium	sweet cherries	0	Kentucky, United States	Number of Responses: 3; Estimated crop value: $37,386*; Estimated crop value lost: $0; For all US Cherry in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Prunus avium	sweet cherries	0.04	Maryland, United States	Number of Responses: 12; Estimated crop value: $171,618*; Estimated crop value lost: $6,865; For all US Cherry in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Prunus avium	sweet cherries	0	Pennsylvania, United States	Number of Responses: 3; Estimated crop value: $1,220,706*; Estimated crop value lost: $0; For all US Cherry in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Prunus avium	sweet cherries	0.1	Virginia, United States	Number of Responses: 3; Estimated crop value: $91,345*; Estimated crop value lost: $9,135; For all US Cherry in 2013: Minimum observed loss: 0; Maximum observed loss: 0.2;	eFly working group, 2014
Prunus avium	sweet cherries	0.24	Maryland, United States	Number of Responses: 4; Estimated crop value: $6,805,024.00; Estimated crop value lost: $1,633,206; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0	Michigan, United States	Number of Responses: 4; Estimated crop value: $98,739,000; Estimated crop value lost: $0.00; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015

Prunus avium	sweet cherries	0.01	North Carolina, United States	Number of Responses: 6; Estimated crop value: $1,597,742; Estimated crop value lost: $15,977.42; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0	New York, United States	Number of Responses: 10; Estimated crop value: $1,073,000; Estimated crop value lost: $0; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0.1	Oregon, United States	Number of Responses: 24; Estimated crop value: $79,168,000; Estimated crop value lost: $7,916,800; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0.01	Virginia, United States	Number of Responses: 10; Estimated crop value: $4,682,131; Estimated crop value lost: $46,821; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0.03	Washington, United States	Number of Responses: 3; Estimated crop value: $515,930,000; Estimated crop value lost: $15,477,900; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0.03	Wisconsin, United States	Number of Responses: 3; Estimated crop value: $1,885,000.00; Estimated crop value lost: $140,490; For all US Cherry in 2014: Minimum observed loss: 0; Maximum observed loss: 1;	eFly working group, 2015
Prunus avium	sweet cherries	0.9	Trentino, Italy	More than 90% of late harvested cherries in some orchards on Vigolana plateau and in Giudicarie Valley were infested by D. suzukii eggs and larvae, even if the insecticides phosmet and acetamiprid had been sprayed at the reddening of the fruits for Rhagoletis cerasi control.	Grassi et al., 2011

Prunus avium	sweet cherries	0.75	Switzerland	Early ripening sweet cherries cultivars are harvested before a significant build-up of D. suzukii populations can occur and hence typically suffer less damage than later ripening cultivars. For example, in 2016, fewer plots of the early cultivars Bigarreau Burlat (24%, N = 78), Grace Star (28%, N = 23) and Merchant (30%, N = 128) were damaged than plots of the later cultivars Schauenberger (92%, N = 72), Star (75%, N = 84) and Sweetheart (72%, N = 25). Growers typically forfeit harvesting heavily infested sweet cherries crops (over 20% of the fruit attacked) because the inspection and selection of fruits become too time-consuming and thus too expensive.	Mazzi et al., 2017
Prunus persica var. nucipersica	nectarine	0.1	New York, United States	Information lacking so same damage as peach assumed. Observed crop loss of 10% for peach in United States, New York 2012. Peach fuzz is protective. And oviposition of occurs on fruit wounds (Andrezza 2017). Oviposition only occurred on fruit wounds (Stewart 2018)	eFly working group, 2012
Prunus persica	peach	0.1	New York, United States	Observed crop loss of 10% in United States, New York 2012. Peach fuzz is protective. And oviposition of occurs on fruit wounds (Andrezza 2017). Oviposition only occurred on fruit wounds (Stewart 2018)	eFly working group, 2012

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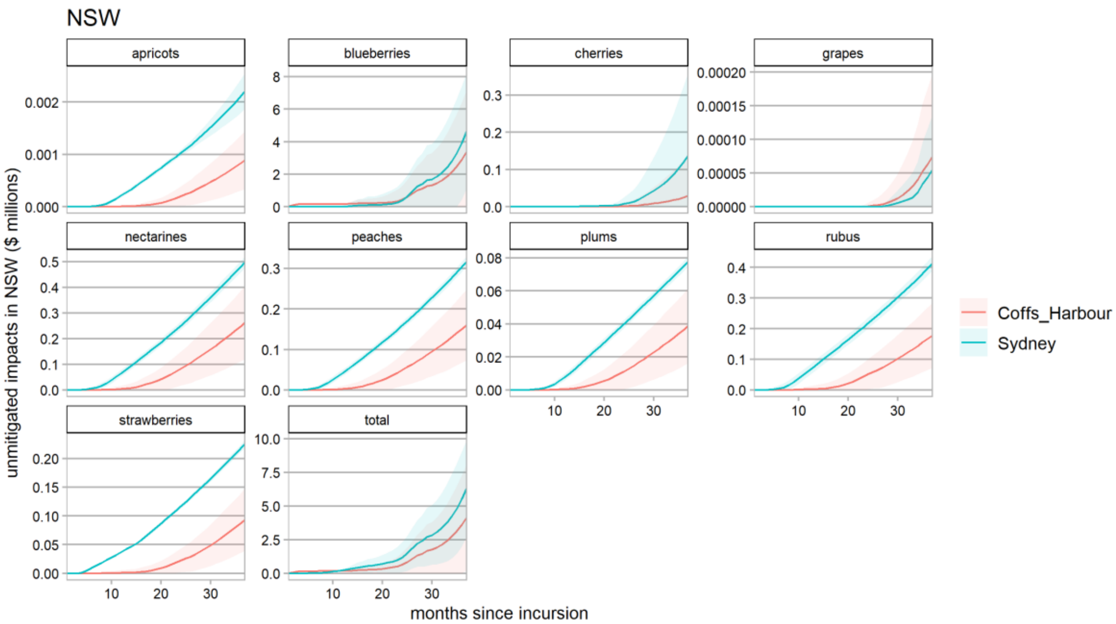
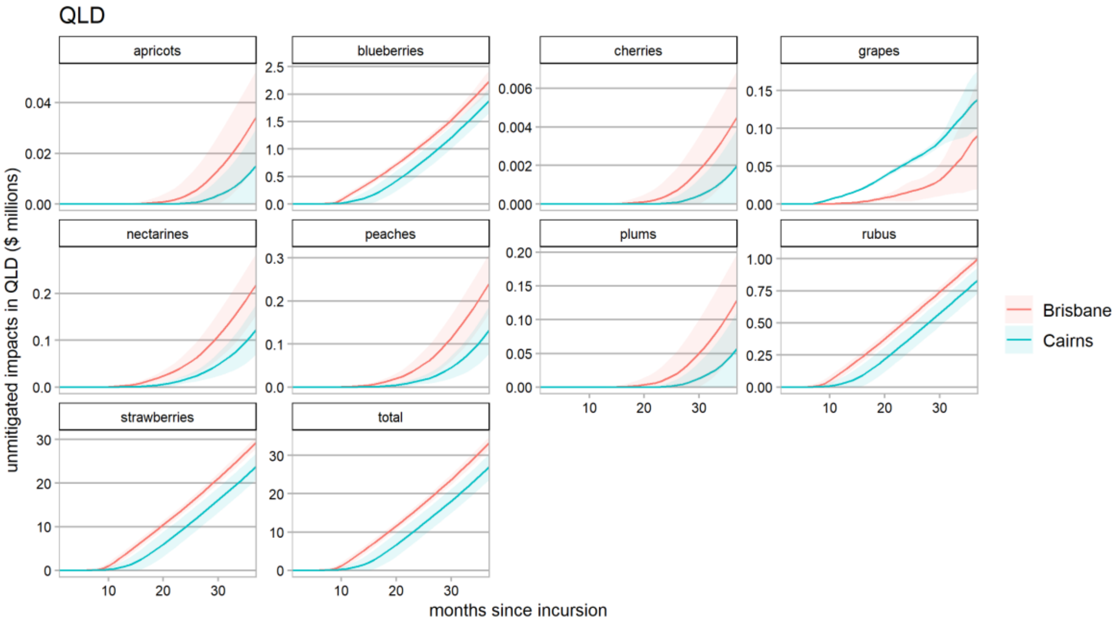
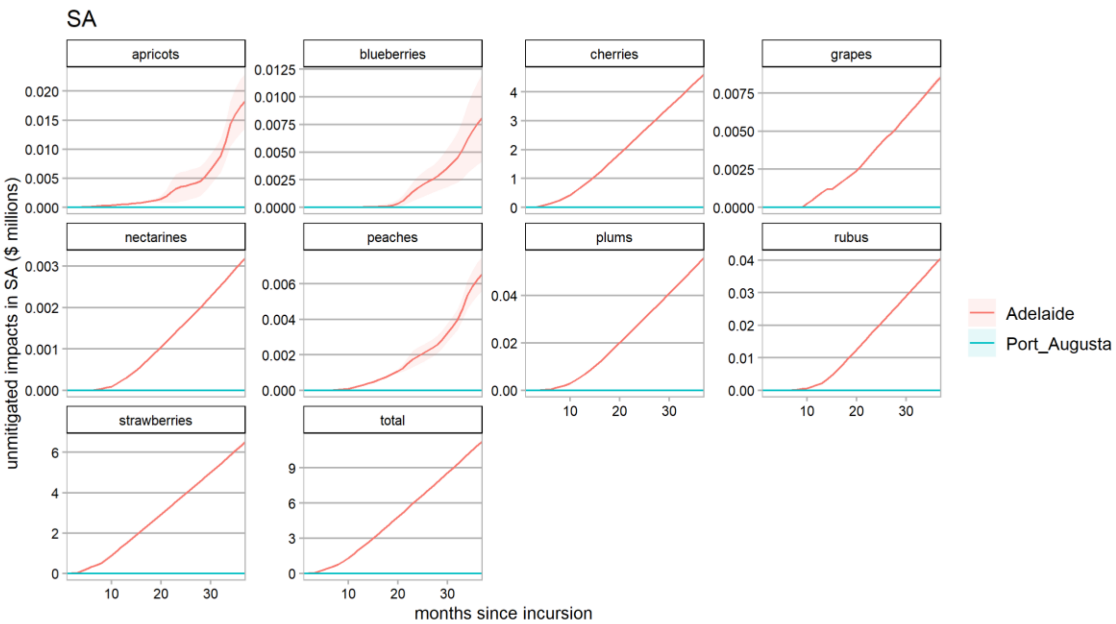
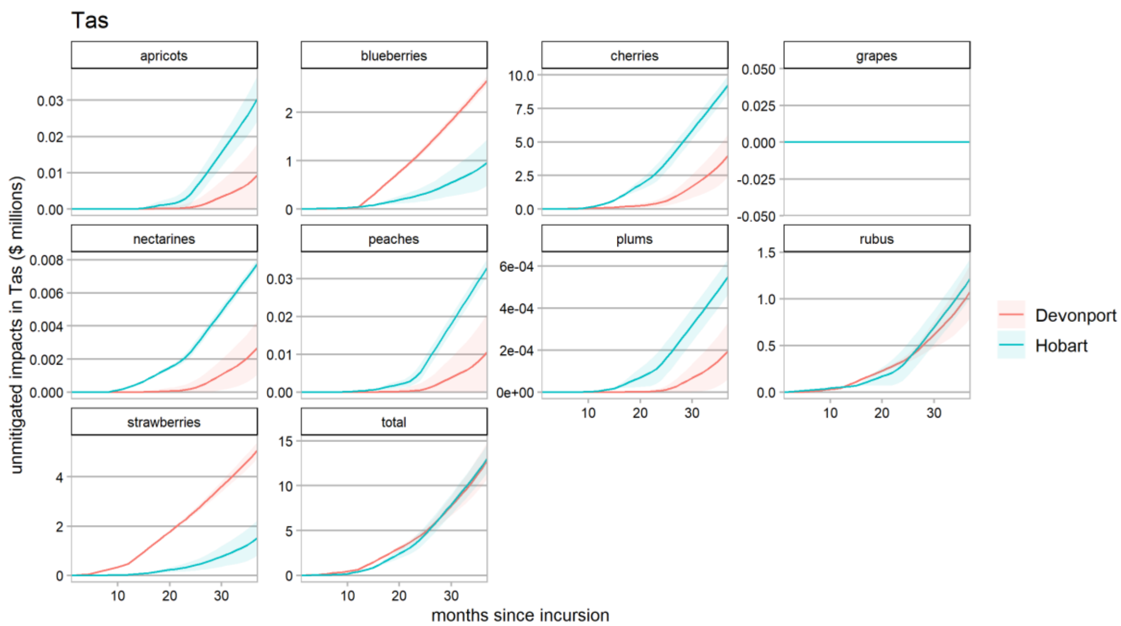
Appendix 2 – Unmitigated impacts of *D. suzukii* incursion across incursion locations and commodities

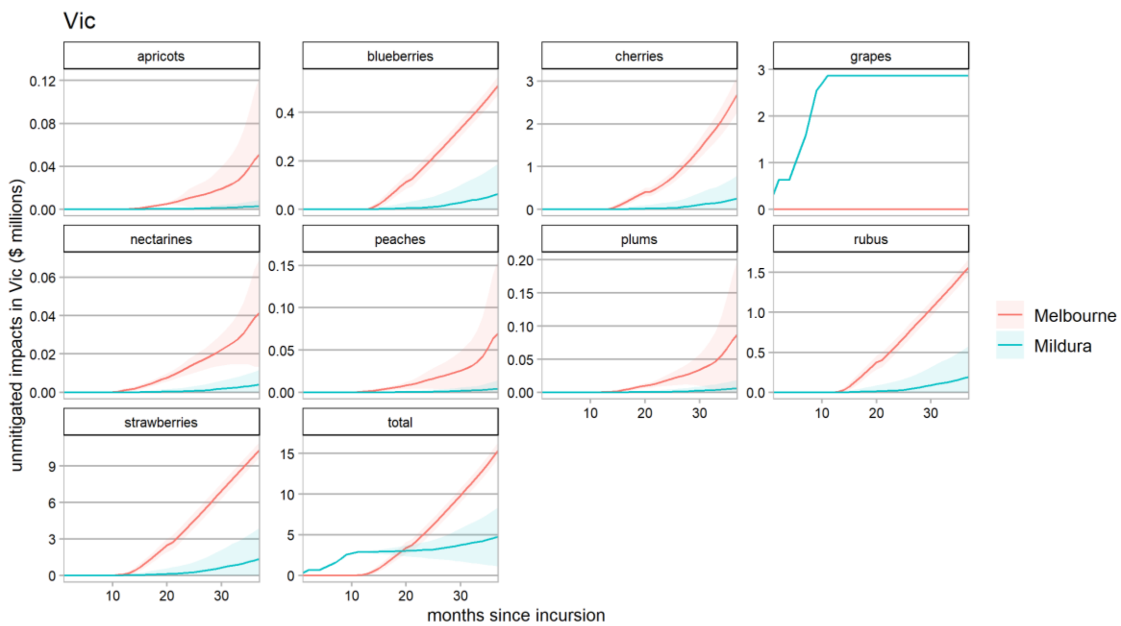
Below we replicate Figure 5, but impacts are only considered in specific jurisdictions to facilitate state and industry level biosecurity response planning. Mean accumulated impacts through time are shown with standard errors of 100 replicated incursions denoted by shaded regions. A time slice of these outputs is provided in the accompanying tables. Note that due to the large variation in impacts both between and within crop (Figure 1), the proportion crop impact was fixed at 10% in order to explore variability due to incursion location and the size and distribution of different soft-fruit production industries.




QLD
apricots
blueberries
cherries
grapes
nectarines
peaches
plums
rubus
strawberries
total
unmitigated impacts in QLD ($ millions)
months since incursion
Brisbane
Cairns


SA
apricots
blueberries
cherries
grapes
nectarines
peaches
plums
rubus
strawberries
total
unmitigated impacts in SA ($ millions)
months since incursion
Adelaide
Port_Augusta


Tas
apricots
blueberries
cherries
grapes
nectarines
peaches
plums
rubus
strawberries
total
unmitigated impacts in Tas ($ millions)
months since incursion
Devonport
Hobart


Vic
apricots
blueberries
cherries
grapes
nectarines
peaches
plums
rubus
strawberries
total
unmitigated impacts in Vic ($ millions)
months since incursion
Melbourne
Mildura

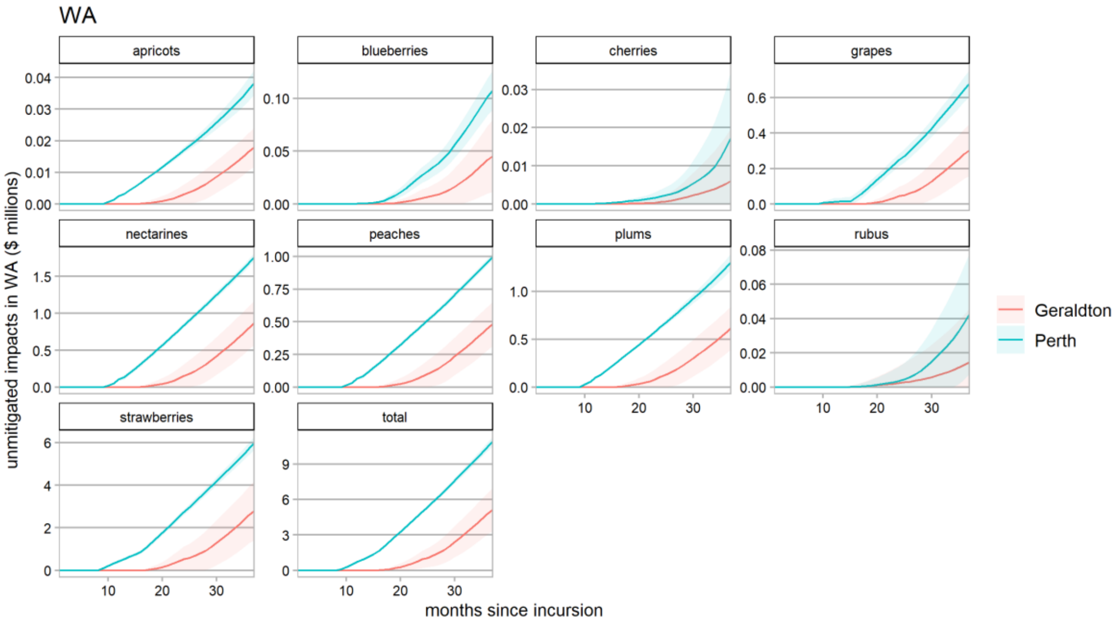

WA
apricots
blueberries
cherries
grapes
nectarines
peaches
plums
rubus
strawberries
total
unmitigated impacts in WA ($ millions)
months since incursion
Geraldton
Perth

Table 3. Accumulated impacts in dollars (millions) across 3 years following *D. suzukii* establishment within each regional jurisdiction, for each commodity and incursion location. Simulations were replicated 100 times with means and standard deviations shown. Due to the large variation in impacts both between and within crop (Figure 1) the proportion crop impact was fixed at 10% in order to isolate uncertainty caused by incursion location and the size and distribution of different soft-fruit production industries.

Jurisdiction	*incursion*	*months since incursion*	*apricots*	*blueberries*	*cherries*	*grapes*	*nectarines*	*peaches*	*plums*	*rubus*	*strawberries*	*total*
Australia	Adelaide	12	0.00 (0.00)	0.00 (0.00)	0.80 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.01)	1.51 (0.05)	2.32 (0.07)
Australia	Adelaide	24	0.01 (0.01)	0.13 (0.25)	2.73 (0.13)	0.01 (0.01)	0.04 (0.06)	0.03 (0.04)	0.04 (0.03)	0.12 (0.15)	5.37 (2.20)	8.47 (2.53)
Australia	Adelaide	36	0.04 (0.06)	1.55 (1.80)	5.44 (0.59)	0.04 (0.07)	0.33 (0.25)	0.22 (0.18)	0.20 (0.20)	0.99 (0.44)	17.54 (6.56)	26.37 (8.38)
Australia	Brisbane	12	0.00 (0.00)	0.40 (0.38)	0.00 (0.01)	0.00 (0.00)	0.01 (0.01)	0.01 (0.01)	0.00 (0.00)	0.15 (0.04)	3.69 (0.94)	4.27 (1.13)
Australia	Brisbane	24	0.01 (0.01)	3.59 (2.12)	0.31 (0.36)	0.04 (0.05)	0.29 (0.12)	0.19 (0.07)	0.08 (0.09)	0.80 (0.16)	17.23 (1.34)	22.55 (2.84)
Australia	Brisbane	36	0.08 (0.08)	13.46 (3.04)	3.25 (1.53)	0.28 (0.16)	1.15 (0.34)	0.82 (0.23)	0.60 (0.29)	2.35 (0.33)	39.26 (2.48)	61.26 (5.04)
Australia	Hobart	12	0.00 (0.00)	0.06 (0.01)	0.39 (0.02)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.06 (0.01)	0.08 (0.21)	0.59 (0.23)
Australia	Hobart	24	0.01 (0.00)	0.60 (0.48)	3.64 (0.70)	0.00 (0.01)	0.09 (0.07)	0.06 (0.04)	0.02 (0.04)	0.58 (0.21)	3.51 (2.79)	8.52 (3.20)
Australia	Hobart	36	0.06 (0.03)	4.00 (2.41)	10.89 (1.00)	0.08 (0.10)	0.51 (0.29)	0.36 (0.19)	0.22 (0.22)	2.72 (0.30)	20.42 (5.64)	39.25 (7.93)
Australia	Melbourne	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.21 (0.13)	0.23 (0.15)
Australia	Melbourne	24	0.01 (0.01)	0.32 (0.27)	0.77 (0.15)	0.00 (0.01)	0.05 (0.05)	0.04 (0.03)	0.03 (0.02)	0.73 (0.12)	5.28 (2.00)	7.23 (2.32)

Australia	Melbourne	36	0.05 (0.07)	1.92 (1.95)	3.13 (0.68)	0.03 (0.07)	0.29 (0.18)	0.22 (0.14)	0.15 (0.16)	1.98 (0.24)	17.57 (5.33)	25.34 (7.16)
Australia	Perth	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.14 (0.03)	0.08 (0.02)	0.13 (0.01)	0.00 (0.00)	0.54 (0.07)	0.91 (0.10)
Australia	Perth	24	0.02 (0.00)	0.05 (0.08)	0.01 (0.03)	0.27 (0.04)	0.91 (0.04)	0.52 (0.02)	0.68 (0.03)	0.02 (0.04)	3.24 (1.00)	5.73 (1.10)
Australia	Perth	36	0.04 (0.01)	0.70 (1.09)	0.24 (0.40)	0.68 (0.08)	1.85 (0.10)	1.06 (0.07)	1.32 (0.09)	0.35 (0.31)	10.41 (4.96)	16.66 (6.27)
Australia	Sydney	12	0.00 (0.00)	0.04 (0.15)	0.00 (0.01)	0.00 (0.01)	0.08 (0.01)	0.05 (0.01)	0.01 (0.00)	0.08 (0.02)	0.12 (0.21)	0.38 (0.30)
Australia	Sydney	24	0.00 (0.01)	0.94 (1.37)	0.18 (0.30)	0.01 (0.05)	0.29 (0.08)	0.19 (0.05)	0.06 (0.06)	0.49 (0.19)	5.33 (3.82)	7.49 (4.90)
Australia	Sydney	36	0.04 (0.04)	6.25 (3.71)	2.19 (1.10)	0.10 (0.14)	0.81 (0.31)	0.53 (0.18)	0.30 (0.23)	1.87 (0.31)	23.29 (4.95)	35.37 (8.33)
NSW	Coffs Harbour	12	0.00 (0.00)	0.18 (0.06)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.01)	0.00 (0.00)	0.00 (0.01)	0.00 (0.01)	0.19 (0.07)
NSW	Coffs Harbour	24	0.00 (0.00)	0.60 (1.03)	0.00 (0.01)	0.00 (0.00)	0.09 (0.07)	0.06 (0.04)	0.01 (0.01)	0.06 (0.05)	0.03 (0.02)	0.85 (1.05)
NSW	Coffs Harbour	36	0.00 (0.00)	3.41 (3.77)	0.03 (0.11)	0.00 (0.00)	0.26 (0.14)	0.16 (0.09)	0.04 (0.02)	0.18 (0.11)	0.09 (0.05)	4.18 (3.93)
NSW	Sydney	12	0.00 (0.00)	0.03 (0.15)	0.00 (0.00)	0.00 (0.00)	0.08 (0.01)	0.05 (0.01)	0.01 (0.00)	0.08 (0.02)	0.04 (0.00)	0.29 (0.15)
NSW	Sydney	24	0.00 (0.00)	0.64 (1.29)	0.01 (0.02)	0.00 (0.00)	0.27 (0.02)	0.17 (0.01)	0.04 (0.00)	0.23 (0.02)	0.12 (0.00)	1.49 (1.29)
NSW	Sydney	36	0.00 (0.00)	4.68 (3.54)	0.14 (0.22)	0.00 (0.00)	0.50 (0.02)	0.32 (0.01)	0.08 (0.00)	0.41 (0.02)	0.23 (0.01)	6.36 (3.58)
QLD	Brisbane	12	0.00 (0.00)	0.26 (0.05)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.15 (0.04)	3.68 (0.95)	4.09 (1.02)
QLD	Brisbane	24	0.00 (0.01)	1.10 (0.07)	0.00 (0.00)	0.02 (0.01)	0.06 (0.03)	0.05 (0.03)	0.02 (0.03)	0.56 (0.04)	15.59 (1.02)	17.40 (1.13)
QLD	Brisbane	36	0.03 (0.02)	2.23 (0.20)	0.00 (0.00)	0.09 (0.07)	0.22 (0.07)	0.24 (0.07)	0.13 (0.07)	1.00 (0.04)	29.33 (1.31)	33.28 (1.60)
QLD	Cairns	12	0.00 (0.00)	0.08 (0.08)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.04 (0.06)	0.98 (1.42)	1.11 (1.54)

QLD	Cairns	24	0.00 (0.00)	0.79 (0.19)	0.00 (0.00)	0.06 (0.00)	0.02 (0.01)	0.02 (0.01)	0.00 (0.01)	0.39 (0.10)	10.95 (2.82)	12.23 (3.08)
QLD	Cairns	36	0.02 (0.01)	1.88 (0.22)	0.00 (0.00)	0.14 (0.04)	0.12 (0.05)	0.13 (0.06)	0.06 (0.05)	0.83 (0.10)	23.86 (2.99)	27.04 (3.32)
SA	Adelaide	12	0.00 (0.00)	0.00 (0.00)	0.79 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	1.50 (0.00)	2.31 (0.01)
SA	Adelaide	24	0.00 (0.00)	0.00 (0.00)	2.67 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.03 (0.00)	0.02 (0.00)	3.97 (0.03)	6.70 (0.03)
SA	Adelaide	36	0.02 (0.00)	0.01 (0.00)	4.61 (0.01)	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)	0.06 (0.00)	0.04 (0.00)	6.52 (0.09)	11.28 (0.11)
SA	Port Augusta	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
SA	Port Augusta	24	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
SA	Port Augusta	36	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Tas	Devonport	12	0.00 (0.00)	0.12 (0.03)	0.09 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.07 (0.00)	0.63 (0.03)	0.91 (0.06)
Tas	Devonport	24	0.00 (0.00)	1.26 (0.06)	0.61 (0.36)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.37 (0.04)	2.63 (0.12)	4.87 (0.48)
Tas	Devonport	36	0.01 (0.01)	2.67 (0.10)	4.01 (1.60)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	1.08 (0.29)	5.09 (0.33)	12.88 (2.03)
Tas	Hobart	12	0.00 (0.00)	0.06 (0.00)	0.39 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.06 (0.00)	0.05 (0.01)	0.55 (0.02)
Tas	Hobart	24	0.01 (0.00)	0.32 (0.15)	3.49 (0.67)	0.00 (0.00)	0.00 (0.00)	0.01 (0.00)	0.00 (0.00)	0.35 (0.17)	0.42 (0.21)	4.60 (0.92)
Tas	Hobart	36	0.03 (0.01)	0.97 (0.48)	9.30 (0.68)	0.00 (0.00)	0.01 (0.00)	0.03 (0.00)	0.00 (0.00)	1.23 (0.21)	1.53 (0.72)	13.10 (1.56)
Vic	Melbourne	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.21 (0.13)	0.23 (0.15)
Vic	Melbourne	24	0.01 (0.01)	0.21 (0.03)	0.75 (0.14)	0.00 (0.00)	0.01 (0.00)	0.02 (0.01)	0.02 (0.01)	0.68 (0.09)	4.53 (0.62)	6.25 (0.83)
Vic	Melbourne	36	0.05 (0.07)	0.51 (0.04)	2.71 (0.42)	0.00 (0.00)	0.04 (0.03)	0.07 (0.09)	0.09 (0.11)	1.57 (0.10)	10.36 (0.63)	15.40 (1.02)

Vic	Mildura	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	2.87 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.01)	0.02 (0.09)	2.89 (0.11)
Vic	Mildura	24	0.00 (0.00)	0.01 (0.04)	0.03 (0.15)	2.87 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.03 (0.13)	0.27 (0.83)	3.21 (1.15)
Vic	Mildura	36	0.00 (0.01)	0.06 (0.13)	0.26 (0.54)	2.87 (0.00)	0.00 (0.01)	0.00 (0.01)	0.01 (0.01)	0.20 (0.39)	1.37 (2.57)	4.77 (3.62)
WA	Geraldton	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.02)	0.00 (0.02)
WA	Geraldton	24	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	0.05 (0.06)	0.18 (0.18)	0.10 (0.10)	0.13 (0.14)	0.00 (0.01)	0.59 (0.65)	1.06 (0.80)
WA	Geraldton	36	0.02 (0.01)	0.05 (0.03)	0.01 (0.01)	0.30 (0.14)	0.87 (0.30)	0.49 (0.17)	0.62 (0.22)	0.01 (0.03)	2.80 (1.39)	5.16 (1.82)
WA	Perth	12	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.13 (0.03)	0.08 (0.02)	0.13 (0.01)	0.00 (0.00)	0.54 (0.07)	0.91 (0.10)
WA	Perth	24	0.02 (0.00)	0.03 (0.01)	0.00 (0.00)	0.27 (0.04)	0.91 (0.03)	0.51 (0.02)	0.68 (0.03)	0.00 (0.01)	2.95 (0.14)	5.38 (0.16)
WA	*Perth*	*36*	*0.04 (0.00)*	*0.11 (0.02)*	*0.02 (0.02)*	*0.68 (0.07)*	*1.76 (0.05)*	*1.00 (0.02)*	*1.31 (0.09)*	*0.04 (0.04)*	*5.97 (0.31)*	*10.92 (0.39)*

Spotted-wing drosophila surveillance, quarantine, and eradication potential in Australia – a benefit-cost analysis

Confidential Report

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Executive Summary

The spotted wing drosophila (*Drosophila suzukii*) has emerged as an international pest that poses a significant threat to Australia's horticultural production. To decide on the appropriate course of action to minimise the impact of an incursion, it is necessary to estimate the outcomes of various surveillance and management options that support suppression, containment, or potential eradication. Importantly, benefits of these interventions, such as the mitigation of industry impacts, must be weighed against their costs, such as the operating costs of surveillance, and disruptions caused by quarantine and pest control measures.

Here, we extend a recently developed spatially explicit simulation framework of population growth and spread, to include surveillance, quarantine, and economic cost processes of *D. suzukii* management and explore the cost-benefits of a range of surveillance and quarantine strategies.

Despite assuming a high efficacy and low cost of quarantine and eradication, as well as optimistic early incursion detection at ports of entry, quarantine and eradication could not be demonstrated as economically rational for simulated incursions of *D. suzukii* into Australia's major coastal cities over a 24-month time horizon. At shorter time horizons (i.e. 12 months), quarantine offered modest benefits in some incursion scenarios, with some support for the cost-effectiveness of eradication in Perth, due to its relative isolation from eastern soft-fruit production regions. The general low cost-effectiveness of the biosecurity responses explored here can be partly explained by *D. suzukii*'s large population growth potential, ability to travel via human-mediated pathways, and low sensitivity of current surveillance methods.

In contrast to eradication and quarantine, increased pest awareness saw large returns on investment due to enhanced early detection and reduced crop losses through appropriate pest management.

Introduction

Spotted wing drosophila (*Drosophila suzukii* (Matsumura)) has emerged as an internationally significant pest of a range of soft-skinned fruits including blueberries, caneberries (e.g. blackberries, raspberries, loganberries and youngberries), cherries, strawberries, summer fruit, and table grapes (Kanzawa 1939; Hauser 2011; Cini et al. 2012; Atallah et al. 2014). While currently absent in Australia, *D. suzukii* poses a major concern to soft-fruit industries (Maino 2020a) with annual production valued at $2.0 billion (HIA 2019). Despite Australia's natural isolation and a rigorous approach to biosecurity, governments have acknowledged that the lack of an established control program could result in significant impacts on horticultural industries (Department of Agriculture Fisheries and Forestry Biosecurity 2013). Fortunately, since 2008, international research has accumulated on ecoclimatic constraints, population dynamics, and monitoring methods. To improve Australia's preparedness response for *D. suzukii*, this accumulated knowledge must be synthesised and interpreted for Australia's unique climatic and production context.

To reduce the impact of an incursion it is necessary to ensure Australian governments and industries are aware of pest establishment and spread risk as well as the effect of risk mitigating activities such as surveillance and control options that support suppression, containment, or potential eradication (Anderson et al. 2017). In Australia, responses are principally decided through the Emergency Plant Pest Response Deed (EPPRD), which is a formal, legally binding agreement between Plant Health Australia (PHA), the Australian Government, all state and territory governments and plant industry signatories, covering the management and funding of responses to emergency plant pests. The EPPRD aims to facilitate a range of agreements and functions that enhance emergency biosecurity responses and reduce the size and impact of an incursion, including a shared role in emergency plant pest response decision making between government and industry and *a priori* cost-sharing arrangements for necessary funding, such as pre-agreed public and private contributions to eradication campaigns undertaken in the event of an incursion (Cook et al. 2010). The EPPRD also aims to facilitate a nationally consistent and agreed approach to incursion management across Australia.

Consistency in biosecurity responses is inherently difficult due to the unique conditions of each incursion (McKirdy et al. 2008). Because of this, expert opinion and qualitative risk assessments frequently form the basis of decision making in the absence of formal quantitative frameworks that incorporate basic pest ecology, expected economic impacts, and the cost-benefit of management responses (McAllister et al. 2017). Integration of these components is critical because they are not independent and thus cannot be addressed separately; unique biological spread and establishment processes will influence efficacy of control measures, total costs, and required management actions. For example, the trapping area and intensity required to delimit an invaded range will be larger for small and highly dispersive pests, and in those locations with environmental conditions most suitable for population growth and spread. This also influences the effect of eradication efforts or quarantine restrictions, and the required sensitivity of surveillance methods and intensity of deployment. Without an integrated framework, it is difficult to quantify the complex impacts of management interventions on rates of spread.

Assuming a management response can be shown to impact pest spread, the benefit-cost of the management response must be considered to determine whether there is a net-benefit of intervention. Costs are incurred through surveillance, eradication, quarantine, and must be weighed against unmitigated costs to industry in terms of pest impacts. A previous study (Maino 2020a), has determined the unmitigated spread and impact potential of *D. suzukii* in Australia is considerable, with unmitigated losses of *D. suzukii* to horticultural industries ranging from $16.6 – 61.3 million following the first 3 years after establishment depending on the location of the incursion and assuming a 10% loss to affected crop production. A remaining task is to quantify the total costs incurred under various management scenarios aiming to mitigate impacts. This will help to select more cost-effective responses that allocate appropriate resources to awareness, surveillance, quarantine, and eradication.

Here, we extend a recent spatially explicit simulation framework of population growth and spread to include surveillance, quarantine, and economic costs to manage *D. suzukii* in the event of an incursion into Australia. This model is used to explore the cost-benefits of a range of impact mitigation strategies. Specifically, we address the following research questions: 1) What is the required surveillance area to delimit spread (e.g. at 6 and 12 months of spread for various incursions points); 2) How does surveillance intensity relate to detection probability; 3) How will different surveillance, quarantine, eradication, and pest awareness scenarios following incursions into major cities affect rates of spread? 4) What is the benefit-cost of these various interventions?

Methods

Incorporating biology, climate, and human population to estimate establishment and spread

We utilise an establishment and spread model for *D. suzukii* developed by the authors and validated against international data on the distribution and spread of *D. suzukii* (Maino 2020b). The density of flies at a given time and location is estimated using a model of climate driven population growth and spread. The pest population growth model captures seasonal environmental suitability, which is important for pests of temperate areas such as *D. suzukii.* The spread model captures both short distance movement through insect flight (Kirkpatrick et al. 2018b), as well as long-distance movement through human-assisted dispersal (Hudgins et al. 2017). The model operates at monthly timesteps to capture seasonal variation in climatic suitability, at a grid size of 9 km. Stochasticity in dispersal processes requires multiple replicate simulations to identify general patterns.

Area of trapping required to delimit spread

During an incursion, it is important to delimit (define the boundaries of) the invaded range so that appropriate response planning can occur. For every ~30 x 30 km region across Australia, we simulate an incursion and estimate the area invaded after 6 and 12 months for 10 replicated simulations assuming no management interventions. The mean area invaded across replicate simulations is reported for each incursion location which is used to generate two maps of Australia where the colour of each location denotes the required trapping area for delimitation after 6 and 12 months. The resulting figures provide an estimate of the predicted spread if initial detection is hypothetically delayed by 6 and 12 months.

The effect of surveillance effort on detection probability

The effect of increased surveillance on detection probability can be estimated if the catch rate is known. To estimate detection probability, detection at each trap is simulated as a random Bernoulli process where the probability of detecting a single fly is specified by p. The number of traps in a cell is defined as T and the number of flies in range of the trap is given by N. Thus, the probability of a detection (d) occurring within the simulation timestep is:

$$d = 1 - (1 - p)^{NT}$$

The number of traps per cell T is a model parameter that is explored in the following analysis, while p is estimated from a previous study measuring catch rates of red sticky traps with a commercial lure under controlled releases of laboratory cultured *D. suzukii* (Kirkpatrick et al. 2018b). Field studies have documented that these trap were reliable in capturing *D. suzukii* and performed similarly to other trap types used for this pest (Kirkpatrick et al. 2018a). The trap was estimated to have an effective radial range of 2.7 ha, across a mean study period of 37.5 d which translate to a monthly catch rate of 0.0041. The number of flies in range of the trap can be estimated by the density of flies per ha multiplied by the effective radial range. The mean number of traps in each cell is defined by the mean trap density T. For any grid cell in the trapping network, trap number is a Poisson variable with rate parameter T.

The impact of management response on rates of spread

Simulated management responses are schematically illustrated in Figure 1. Rather than assuming traps for *D. suzukii* are deployed widely across Australia prior to initial incursion, which would be cost-prohibitive at any meaningful scale, we assume only sentinel surveillance traps are deployed for *D. suzukii* around key ports of entry prior to incursions. Detections can either occur through early detection via surveillance, or through late detection via reports from the general public (we assume a general public report occurs once population densities exceed half the carry capacity i.e. N_D = 5 flies per m²). Following each new detection (early or late), the assumed management response is to conduct additional surveillance around the point of detection, where surveillance is conducted at all grid cells surrounding the detection at a trapping density of T. This adaptive surveillance response is typical during incursions of biosecurity threats (Anderson 2017).
Unlike surveillance, which does not by itself impact rates of spread, other management responses will reduce the rate at which *D. suzukii* can disperse across the landscape. There are two additional types of management response processes we consider here: local eradication, and local quarantine.

Local eradication through appropriate control measures (e.g. pesticide application and host plant removal) are assumed to occur after a trap detection. Population control is assumed to impact the population size in the grid cell in proportion to the strength of the control E_E. We explore local eradications at two levels of efficacy: no population control (0% efficacy); and high control (99.99% efficacy).

Local quarantine is assumed to affect the rate at which human-mediated dispersal occurs from each grid cell in which a population has been detected (either through early or late detections) but does not affect local spread through pest movement (i.e. flight). Local quarantine restricts the human-mediated propagules by a proportion that relates to quarantine efficacy E_Q. We explore local quarantine at two levels: no quarantine (0% efficacy); and quarantine (99.99% efficacy).

For each combination of management response settings for the response modules (local eradication and quarantine), spread is simulated for incursion scenario across Australian capital cities (Melbourne, Adelaide, Brisbane, Hobart, Perth, and Sydney) across three years as these were identified as likely incursion points due to import volume of affected produce and human activity (Maino 2020c). As sentinel surveillance was assumed to occur in these incursion locations, initial detection is optimistically taken to be early during the incursion (i.e. within the first month). This was to simplify the analysis and because rates of spread after 6 and 12 months are explored in the previous section for all possible incursion locations at a 30 km² scale throughout Australia, and can be used to adjust results. Simulations for each unique quarantine settings are replicated 5 times to capture stochasticity in spread processes. The mean area invaded after 24 years for each unique quarantine setting is reported and displayed in a multifaceted plot.

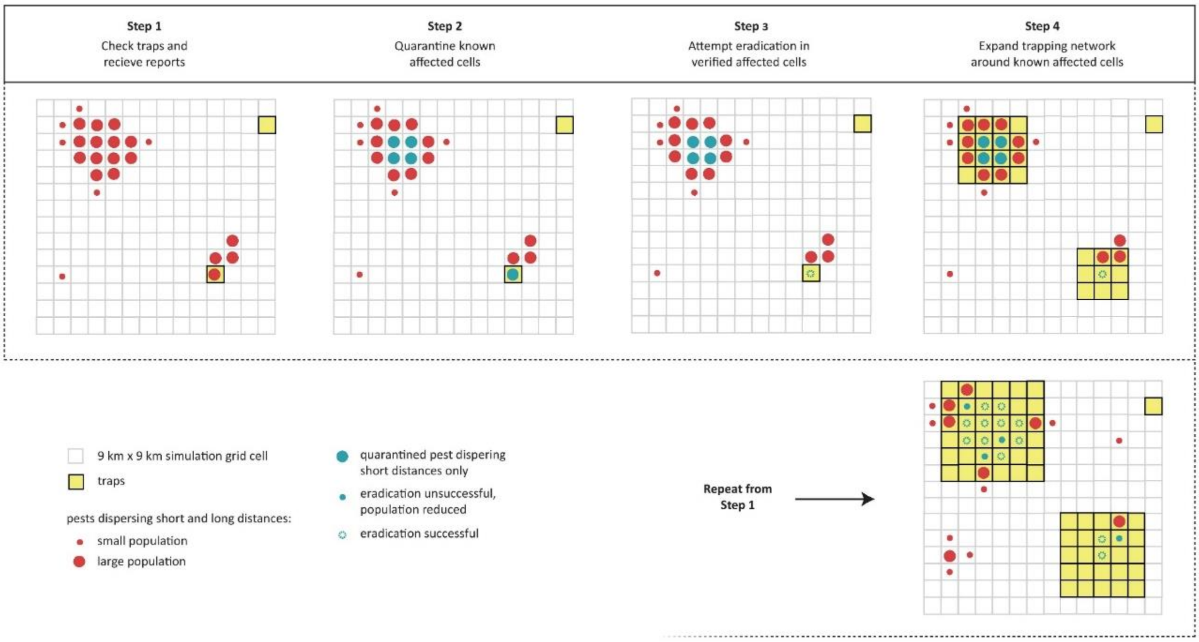

Figure 1. Schematic of pest spread, surveillance, quarantine, and eradication. Step 1: prior to any confirmed detections, traps may be deployed in areas the pest is present or absent; Step 2: early detections occur from trapping, which may detect small populations, while late detections occur through public reports of large populations; Step 3: all detections are quarantined, while eradications are attempted only for detections confirmed by trapping; Step 4: trapping is expanded around areas of early and late detections. Each step is completed for each round (only Step 4 is shown for Round 2).

The impact of increased pest awareness

Increased awareness of biosecurity threats can increase likelihood of early detection (Piola and McDonald 2012) and reduce production impacts through appropriate management (Maino 2020a). To explore these effects, we assume that under a high pest awareness scenario, pests are detected at damaging levels of 1000 flies/ha or 0.1 flies/m^2 (Kirkpatrick et al. 2018b) and that impacts to farm income are modestly reduced from 10% to 5% of the crop value, which was shown to be realistic after new management practices, such as new chemical management or crop hygiene, are adopted by farmers (de Ros et al. 2015; Farnsworth et al. 2017; Maino 2020a). Thus, ongoing management costs by growers, such as increased chemical costs associated with pesticides, increased labour associated with crop hygiene, and remaining yield losses due to pest damage, are implicitly reflected in the 5% loss of gross production value of affected commodities.

Cost-benefit of management responses

Increased surveillance, awareness and management responses will decrease the spread of *D. suzukii*, but not without costs. Understanding the relationship between different management scenarios and total costs incurred (in terms of impacts and management) is essential to making decisions that will reduce total economic impacts of an incursion. In the following we explore the total costs incurred in each of the scenarios defined in the previous section, where total costs include costs of surveillance, eradication, quarantine, and industry losses. Following Maino (2020a) the gridded annual production value of affected commodities is estimated from available economic and land usage (ABARES 2018; ABS 2018).

Total annual surveillance costs C_S are assumed to scale with the number of traps T in the surveillance network, or $C_S = c_T T$ where c_T is the cost of operating each trap across one year.

The cost of local eradication C_E is assumed to scale linearly with the efficacy of control E_E, and the size of the area under eradication A (Tobin et al. 2014) and can be expressed as $C_E = c_E A E_E$ where c_E is the cost of eradication at maximum efficacy. The cost of local movement control C_Q is assumed to scale linearly with efficacy of control E_Q, and the annual value of commodities affected by local quarantine V_Q and can be expressed as $C_Q = V_Q E_Q$. This assumes the entire value of production is sacrificed, but ignores additional costs of maintaining a quarantine zone, including communications and compliance.

Industry losses C_I are assumed to include the value of crop losses due to *D. suzukii* infestations and can be calculated as a proportion c_I of the annual value of commodities produced in each cell where populations of *D. suzukii* are present V_I. This can be expressed as $C_I = c_I V_I$.

Estimates of these costs were generated through discussions with the chief plant health officers across Australian jurisdictions and available literature as summarised in Table 1. These fixed parameters were used in simulations where free parameters (e.g. trap density) were varied to explore the effect of management responses (e.g. higher trap density) across all parameter combinations. To obtain a measure of uncertainty, each unique combination of parameters was repeated in 5 replicate simulations.

Table 1. Parameters for surveillance, quarantine and cost scenarios used in simulations of management effect and associated costs. Free parameters are used to explore different management options.

FIXED PARAMETERS	**DESCRIPTION**	**VALUE**	**JUSTIFICATION**
p	Trap detection probability (1/d)	0.0041	(Kirkpatrick et al. 2018b)
c_T	Cost of trap operation ($/year)	1,000	(Hardie, *pers. comms*)
c_E	Cost of eradication at maximum efficacy ($/km²/year)	300,000	(Mazzi et al. 2017)
c_V	Unmitigated crop loss (%)	10%*	(Maino 2020a)
c_S	Maximum local quarantine cost as a proportion of crop value, scaled by quarantine efficacy (%)	100%	All produce under quarantine is taken as sacrificed during an incursion
N_D	Threshold *D. suzukii* density for late detection (i.e. through public observations), no./m²	5*	This is taken as half the environmental carrying capacity.
FREE PARAMETERS			
T	Trap density (traps/km²)	(0.1, 0.0001, 0.001, 0.01, 0.1, 1.0)	
E_E	Strength of local eradication (%)	(0%, 99.99%)	
E_Q	Strength of local quarantine (%)	(0%, 99.99%)	

*Under the scenario of increased pest awareness, impacts to farm revenue are reduced from 10% to 5% and the detection threshold is reduced from 5 flies/m² to 0.1 flies/m² following (Maino 2020a) and (Kirkpatrick et al. 2018b). The cost of increased awareness is arbitrarily (though conservatively) taken as $1 million dollars.

Results and Discussion

Area of trapping required to delimit spread

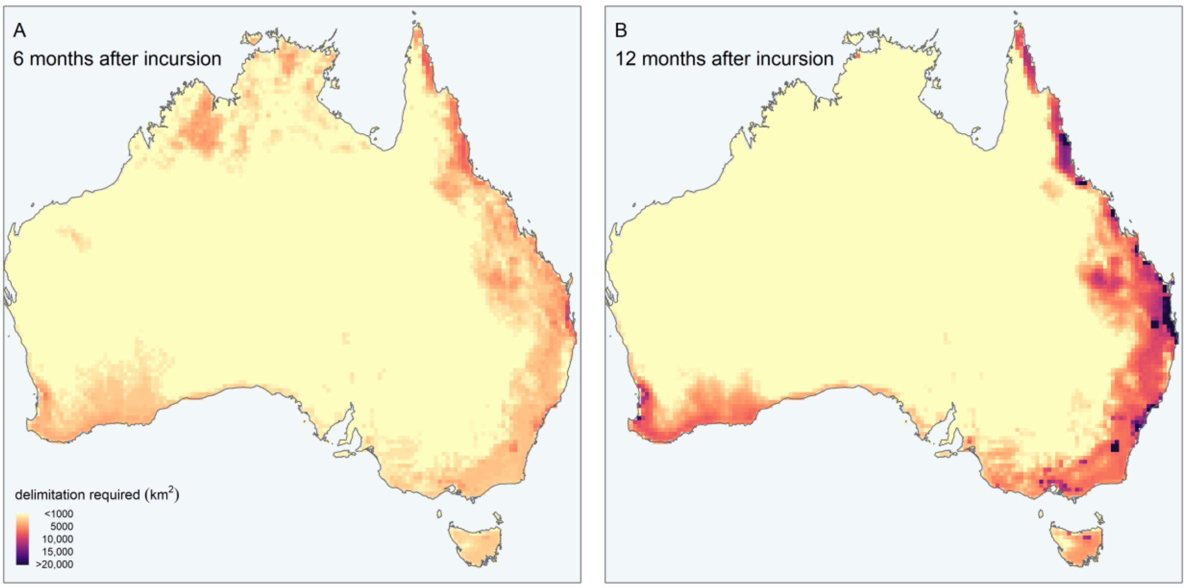

Figure 2. Area delimitation required for a simulated incursion at each grid cell after 6 months (A) and 12 months (B). The colour for each pixel indicates the spread potential and thus delimitation requirements for an incursion originating at each pixel. The area of trapping required to delimit spread depends on the duration since the initial incursion, and on the environmental conditions and human population density at the incursion point. For each pixel, the mean of 10 replicate simulations is shown.

Following an incursion of *D. suzukii*, the area of trapping required to delimit spread depended on the duration since the initial incursion, and on the environmental and human population density at the incursion point (Figure 2). Following an incursion, *D. suzukii* was estimated to have spread on average 2041 km^2 after 6 months and 4674 km^2 after 12 months from the point of initial incursion when considering cells where spread is possible (e.g. ignoring spread rates in the interior of Australia, which were too hot and dry for the pest to persist). In addition to the time since incursion, the environmental conditions and human population density at an incursion location was a major driver in spread rates which will influence the area required to be under surveillance for delimitation purposes. For example, coastal regions on the east coast with high population densities will require greater delimitation efforts for an incursion originating here. Conversely, if an incursion commenced at inland locations with poorer climatic suitability and lower population densities, the incursion extent could be more readily delimited or the population may die out without any intervention. If incursions begin at major cities, due to rapid spread, there will be increased difficulty in pinpointing the origin of the incursion.

Trade-off between surveillance effort and probability of detection

Estimating the effect of surveillance effort on detection probability showed that even a large surveillance effort of 1 trap per hectare only provides ~50% confidence that the trap will detect densities of *D. suzukii* of 100 per ha (Figure 3), which is a sufficiently large density to cause crop losses (Kirkpatrick et al. 2018b). Naively assuming 1 trap per hectare in Australia's approx. 70,000 ha of horticultural regions (Bureau of Agricultural and Resource Economics and Sciences 2010) would result in an annual surveillance operating cost of over $70 million if annual operating costs per trap with weekly inspections are taken as $1000. For this reason, the following scenarios deal with a more dynamic surveillance response, where surveillance was first prioritised at ports of entry and then expanded following each new positive detection.

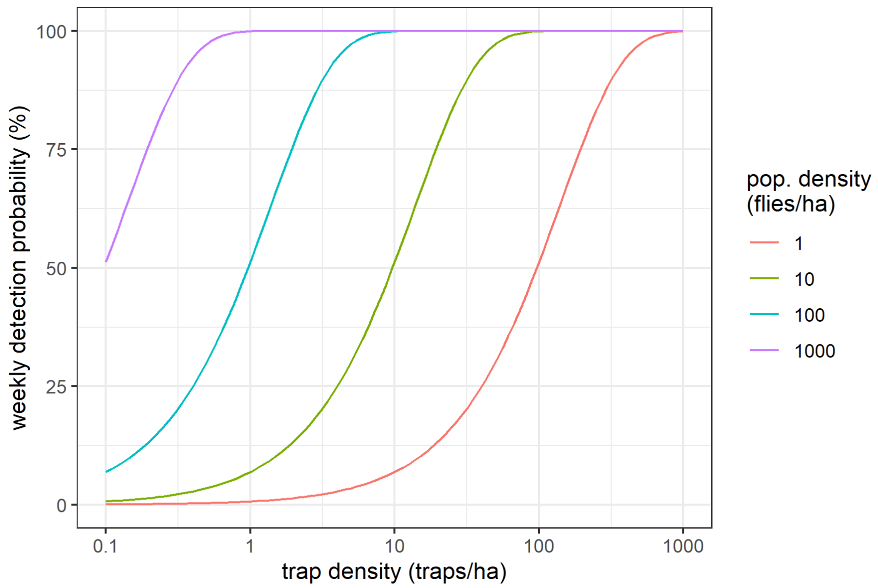

Figure 3. The estimated trade-off between surveillance effort and the probability of detection based on release and recapture study (Kirkpatrick et al. 2018b) for a single 20 × 30 cm double-sided, sticky, red panel trap (Great Lakes IPM, Vestaburg, MI) baited with a commercial *D. suzukii* lure (Scentry Biologicals, Billings, MT) placed in the bottom third of the canopy of a cherry tree.

The impact of management response on rates of spread

Under a variety of different management options and incursion scenarios, some general patterns emerged with respect to the estimated invaded area of *D. suzukii* after 24 months (Figure 4). All incursion scenarios are included in Appendix 1, but in the following we focussed on the high-risk Brisbane incursion scenario identified in Figure 2 to demonstrate how results can be used for region specific management recommendations.

As expected, spread was minimised when surveillance trap density, eradication, quarantine, and pest awareness were at highest levels (Figure 4). Quarantine decreased rates of spread across all scenarios due to surveillance trapping and public pest reports, however eradication only substantially reduced spread rates when trapping was suitably dense. At low trap densities, spread to new cells remained undetected until large populations sizes triggered late reports. Despite the assumed 99.99% eradication efficacy, and the early detection (sentinel traps in proximity of the initial incursion), eradication required high trapping densities to meaningfully reduce rates of spread. This reflects the low capture rate of current surveillance tools for *D. suzukii*, coupled with its large capacity for human mediated spread. As found earlier, the higher density of 0.1 trap per hectare (10 traps/km^2) only provides ~50% confidence that the trap will detect densities of *D. suzukii* of 1000 flies/ha, well in excess of damaging densities. In contrast, the strong effect of quarantine reduced spread rates substantially, which reflects the large capacity for the pest to travel along human-mediated pathways. High pest awareness reduced rates of spread under quarantine and eradication scenarios due to earlier public reporting and subsequent application of response tools (Figure 4).

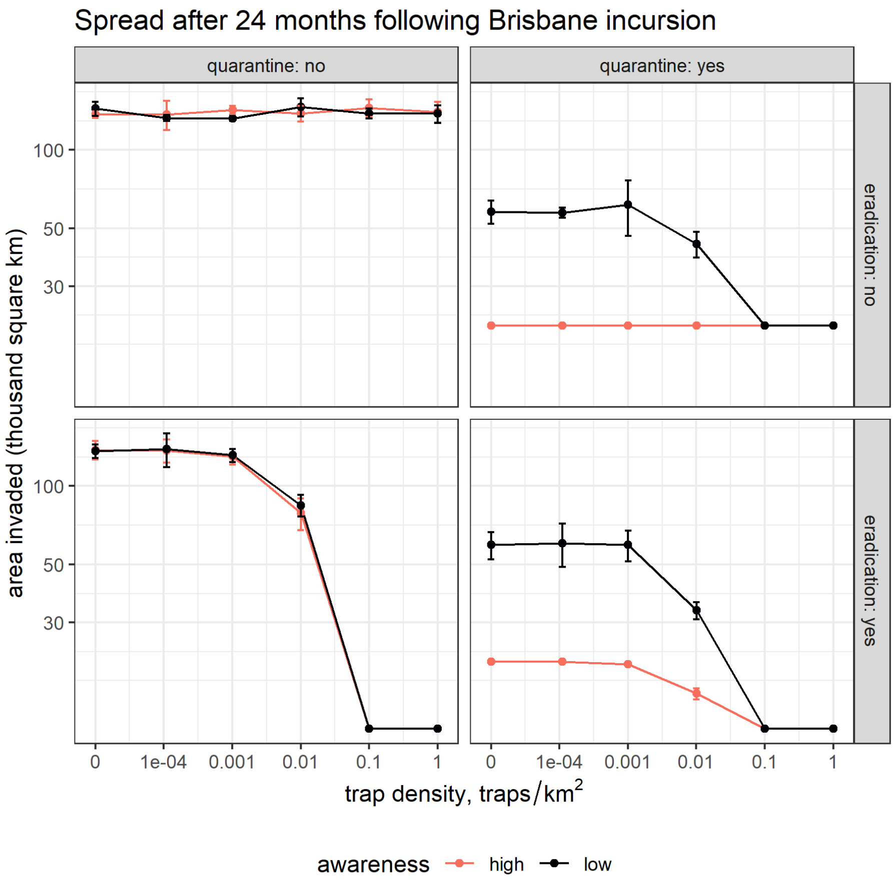

Figure 4. Estimated area invaded after 24 months following a Brisbane incursion with various management response settings. Trap density denotes the mean density of traps in each square kilometre. Eradication denotes reduction of populations to 99.99% of the maximum population in locations at which presence of *D. suzukii* has been confirmed through surveillance trapping. Quarantine denotes a 99.99% reduction in populations dispersing by human means in locations where the fly has been reported or trapped. Awareness denotes the level of pest awareness among the public, where a high pest awareness leads to early public reporting once the pest exceeds damage levels of 0.1 individuals/m^2 compared with (5 individuals/m^2 under low awareness). Bars denote standard error across 5 replicate simulations. Summary plots for other incursion locations can be found the appendix.

Cost-benefit of management responses

Incorporating costs into management (Figure 5) produced different recommendations compared to when only spread rates were considered (Figure 4). Namely, despite the large effect of quarantine and eradication in reducing spread rates, it did not emerge as cost-effective after 24 months in any of the simulations conducted for the Brisbane incursion (Figure 5). This was in spite of the high eradication efficacy (99.99% population reduction, which reduced carrying capacity of flies to under 2 individuals/ha), the low estimated cost of eradication (\$300,000 / km^2 / year) and quarantine (only the value of production was sacrificed), and perfect compliance (all pests were reported once detection thresholds were passed). In these high investment scenarios, *D. suzukii* was predicted to continue to spread through time, though at far slower rates compared with scenarios without any investment in responses (Figure 7). Higher costs and/or worse compliance would further reduce cost-effectiveness. Some strategies with eradication were associated with relatively low costs, but this result was driven by the lack of trapping (and thus low total number of regions to which eradication was applied).

After 24 months following the Brisbane incursion, the most cost-effective management response involved only increased pest awareness (Figure 5). Despite the high initial investment in public awareness of $1 million, this approach led to considerable cost-savings compared with scenarios with low pest awareness due to the mitigated impacts through appropriate management. This also considerable increased the cost effectiveness in situations where eradication was attempted due to enhanced reporting, which led to more efficient surveillance trapping.

For other incursion scenarios in other major cities, the management responses that minimised total impacts are summarised in Table 2. Simulations for these other incursions confirm that after 24 months, the management response that minimised total costs included high pest awareness without eradication or quarantine.

However, across a shorter time period of 12 months, quarantine with moderate surveillance became cost-effective for Melbourne and Perth incursion scenarios, reflecting the importance of time horizons in the calculation of benefit-costs. Indeed, even for the Brisbane incursion, the large errors bars for quarantine scenarios (Figure 5) indicate that, due to stochasticity in spread, some simulations with quarantine were more cost-effective, just not on average. There was also some support for eradication in Perth, due to its relative isolation from eastern soft fruit industries. Though It is important to reiterate that the cost-effectiveness of quarantine and eradication depends on the early detection, reliability of public reporting at high densities, and high compliance with quarantine restrictions (99.99%). In contrast to quarantine, investment in increased pest awareness only saw a net benefit for Adelaide and Melbourne simulations by 12 months. This reflects that time taken to recover the large initial investment in education. By 24 months, investment in pest awareness resulted in the lowest overall impacts across all incursion scenarios tested.

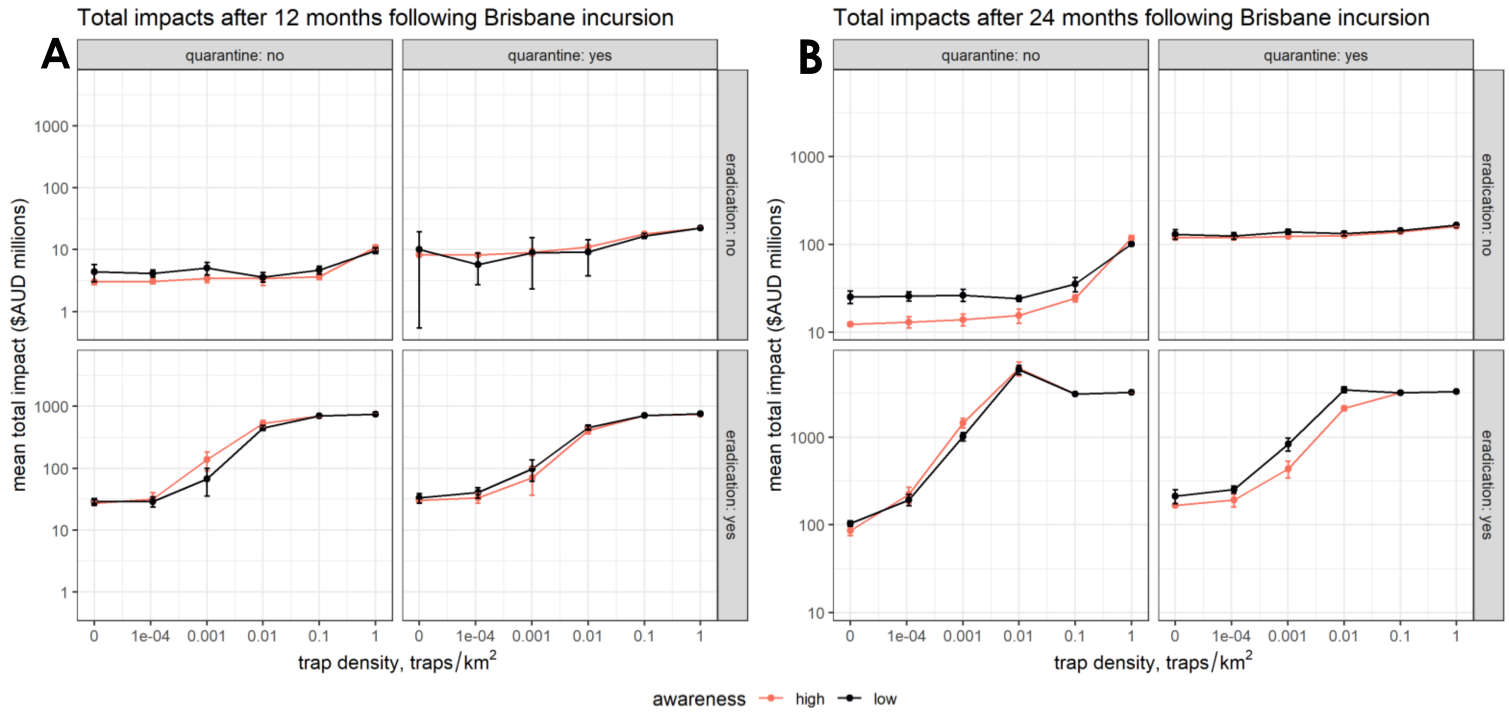

Figure 5. Estimated total costs (crop loss, pest management, eradication, quarantine, and awareness) after 12 (A) and 24 (B) months following a Brisbane incursion with various management response settings. Trap density denotes the mean density of traps in each square kilometre. Eradication denotes reduction of populations to 99.99% of the maximum population in locations at which presence of *D. suzukii* has been confirmed through surveillance trapping. Quarantine denotes a 99.99% reduction in populations dispersing by human means in locations where the fly has been reported or trapped. Awareness denotes the level of pest awareness among the public, where a high pest awareness leads to early public reporting once the pest exceeds damage levels of 0.1 individuals/m^2 (from 5 individuals/m^2 under low pest awareness) and crop losses reduced to 5% (from 10% under low pest awareness). Bars denote standard error across 5 replicate simulations. Summary plots for other incursion locations can be found the appendix.

Table 2. Lowest cost management response at 12- and 24-month time horizons calculated from the mean of five replicate simulations for incursions at major capital cities. Management responses indicate the actions taken for the lowest impact scenario.

INCURSION	12 MONTHS		24 MONTHS	
	Management responses	**Total cost ($ million)**	**Management responses**	**Total cost ($ million)**
Adelaide	awareness	2.62	awareness	5.36
Brisbane	awareness	3.54	awareness	13.53
Hobart	no response	1.54	awareness	6.87
Melbourne	quarantine trap density 0.001	0.59	awareness	5.47
Perth	eradication quarantine trap density 0.001	1.66	awareness	4.54
Sydney	no response	0.57	awareness	3.90

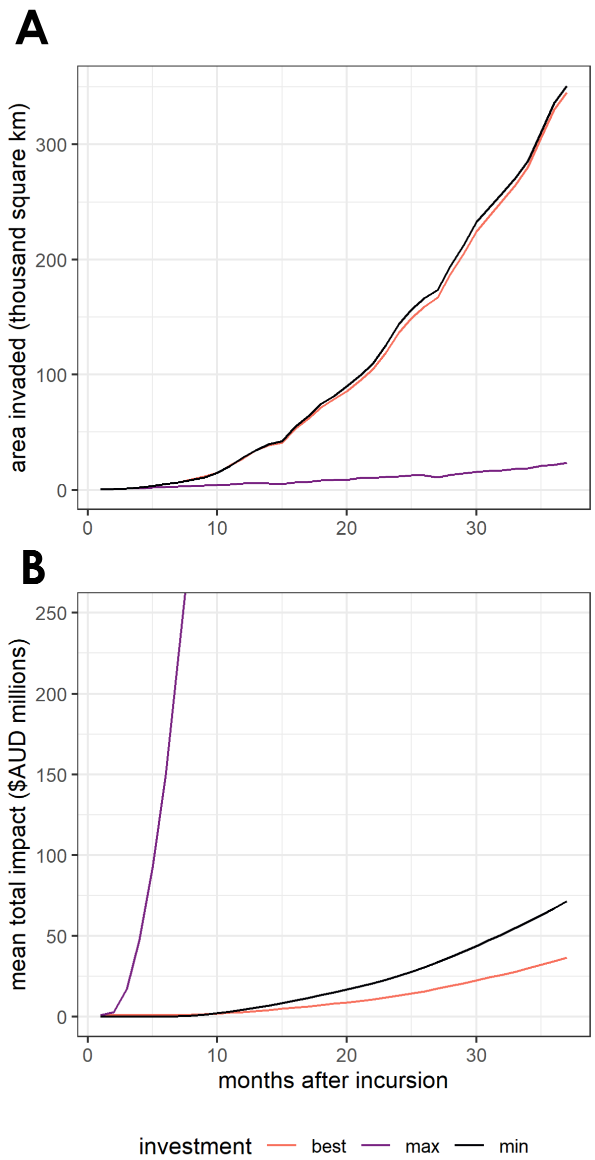

Figure 7. Area invaded (**A**) and cumulative total cost of impacts (crop loss, pest management, eradication, quarantine, and awareness) (**B**) through time following an incursion into Brisbane. Different lines denote a subset of the investment scenarios where "max" denotes maximum investment (eradication, quarantine, awareness, and trapping densities of 1 trap/km^2), "min" denotes minimum investment (no eradication, quarantine, awareness, nor trapping), and "best" denotes the most cost-effective investment tested (increased pest awareness without eradication, quarantine, or trapping).

Conclusion

Despite the high efficacy and low costs assumed across of quarantine, eradication, and early detection (at ports of entry), quarantine and eradication did not prove economically rational in simulated incursions of *D. suzukii* into major coastal cities for a 24-month time horizon. At shorter time horizons (i.e. 12 months) quarantine offered modest benefits in some incursion scenarios, with some support for eradication being cost-effective for short time frames in Perth (assuming early detection). This general low-cost effectiveness of common management responses can be explained by *D. suzukii*'s large population growth potential, ability to travel via human-mediated pathways, and low sensitivity of current surveillance methods (Kirkpatrick et al. 2018b). In contrast to eradication and quarantine, increased pest awareness saw large a return on investment due to enhanced early detection and/or reduced crop losses through appropriate pest management. This finding may be supported by recent Australian experiences with invasions of myrtle rust (Carnegie and Pegg 2018) and Panama disease (Panama Tropical Race 4) in bananas (Maclean et al. 2018) where the sub-optimal resourcing for public awareness and social resilience was identified in biosecurity responses.

Acknowledgments

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Hort Innovation

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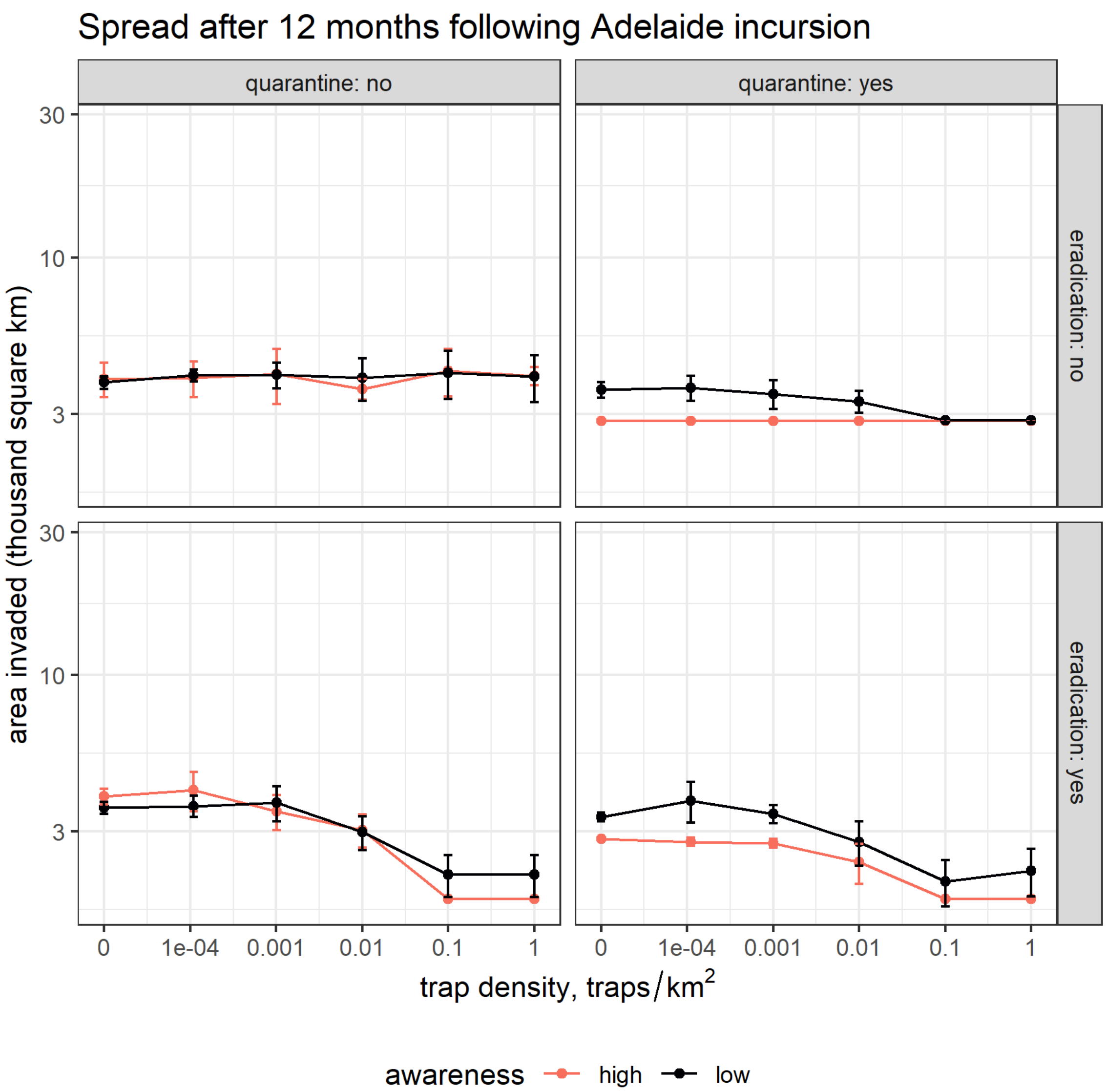
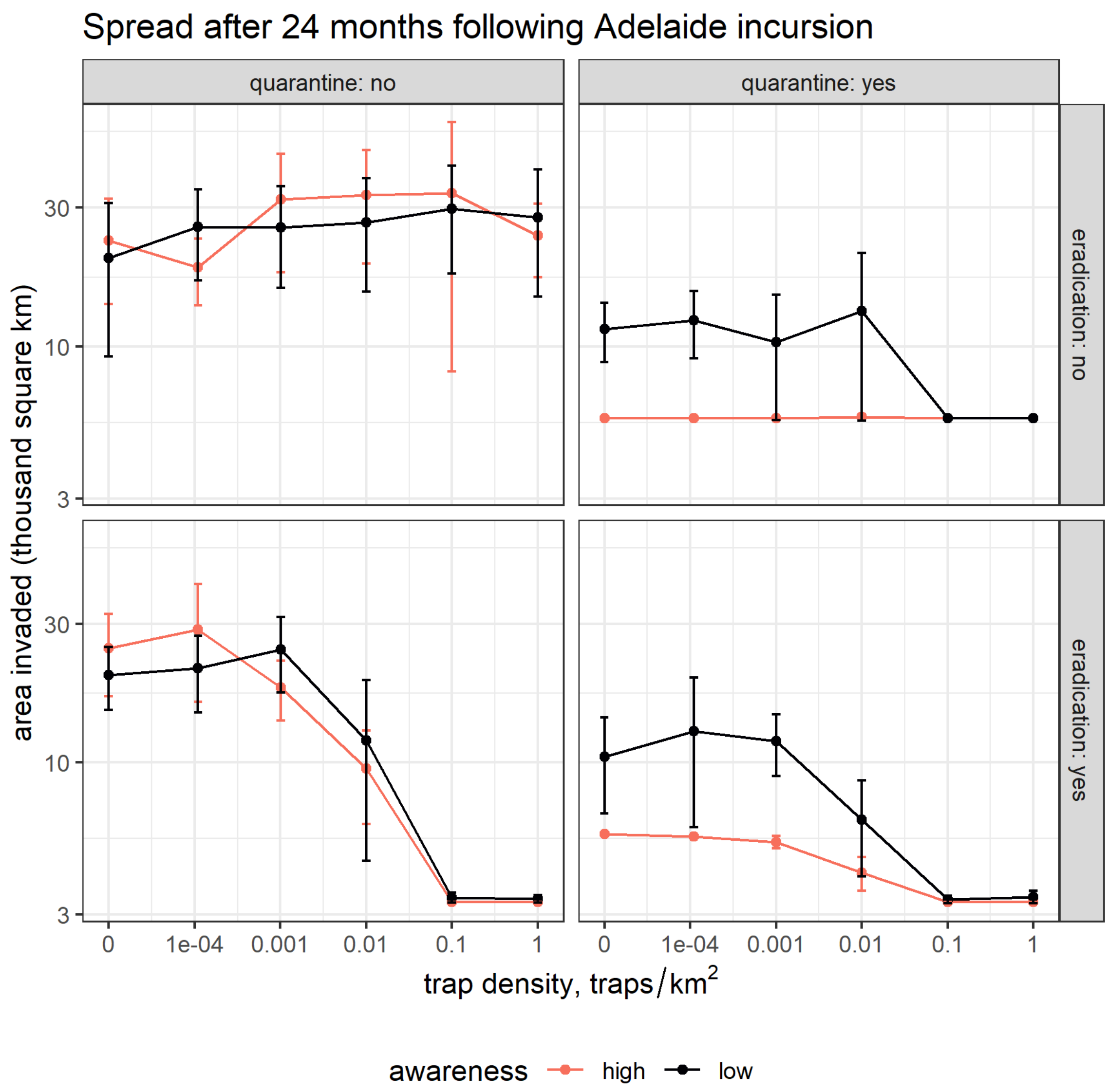
Supplementary figures – Replotting of figures 4 and 5 for simulated incursions into other ports of entry

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awareness
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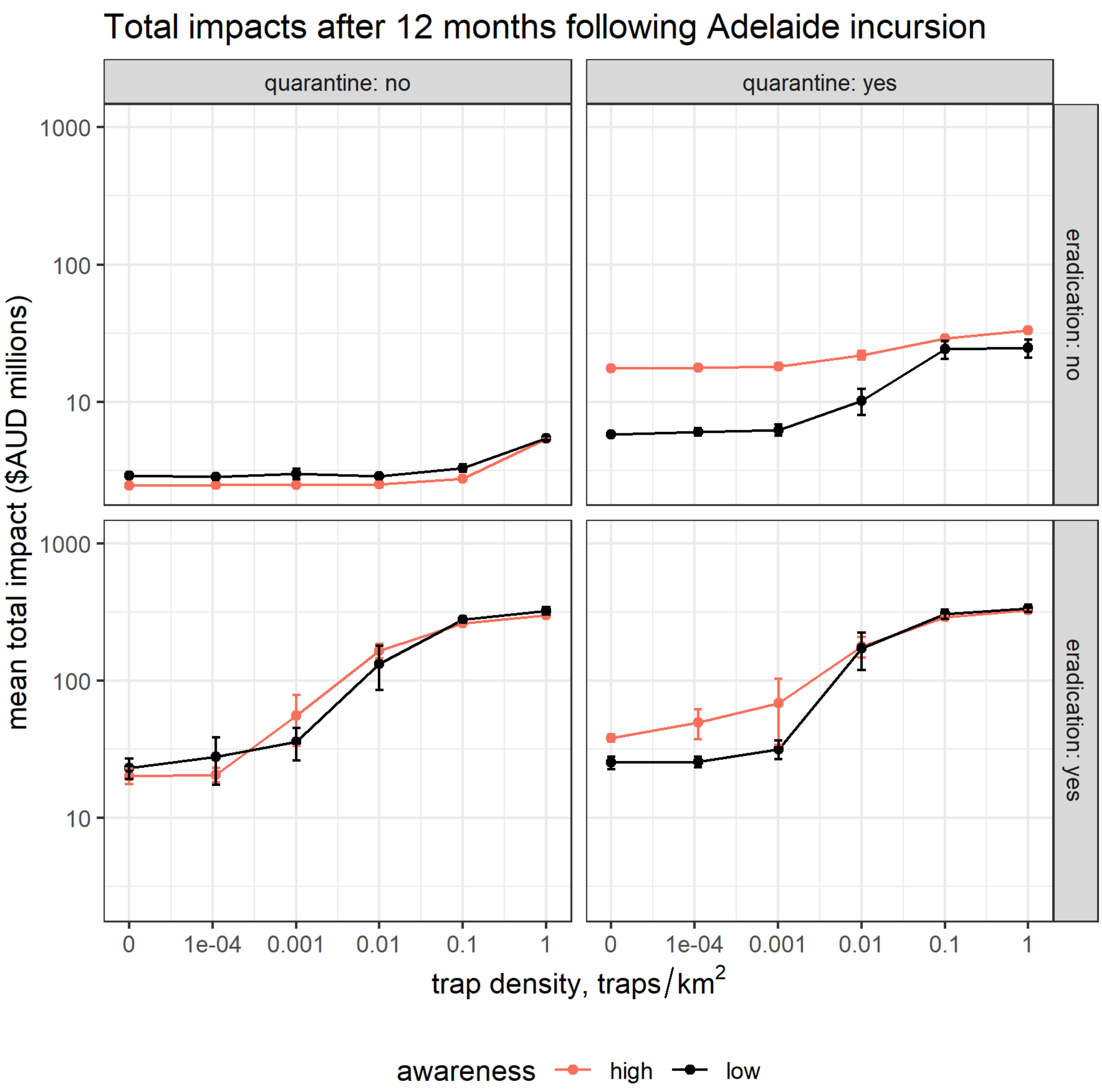
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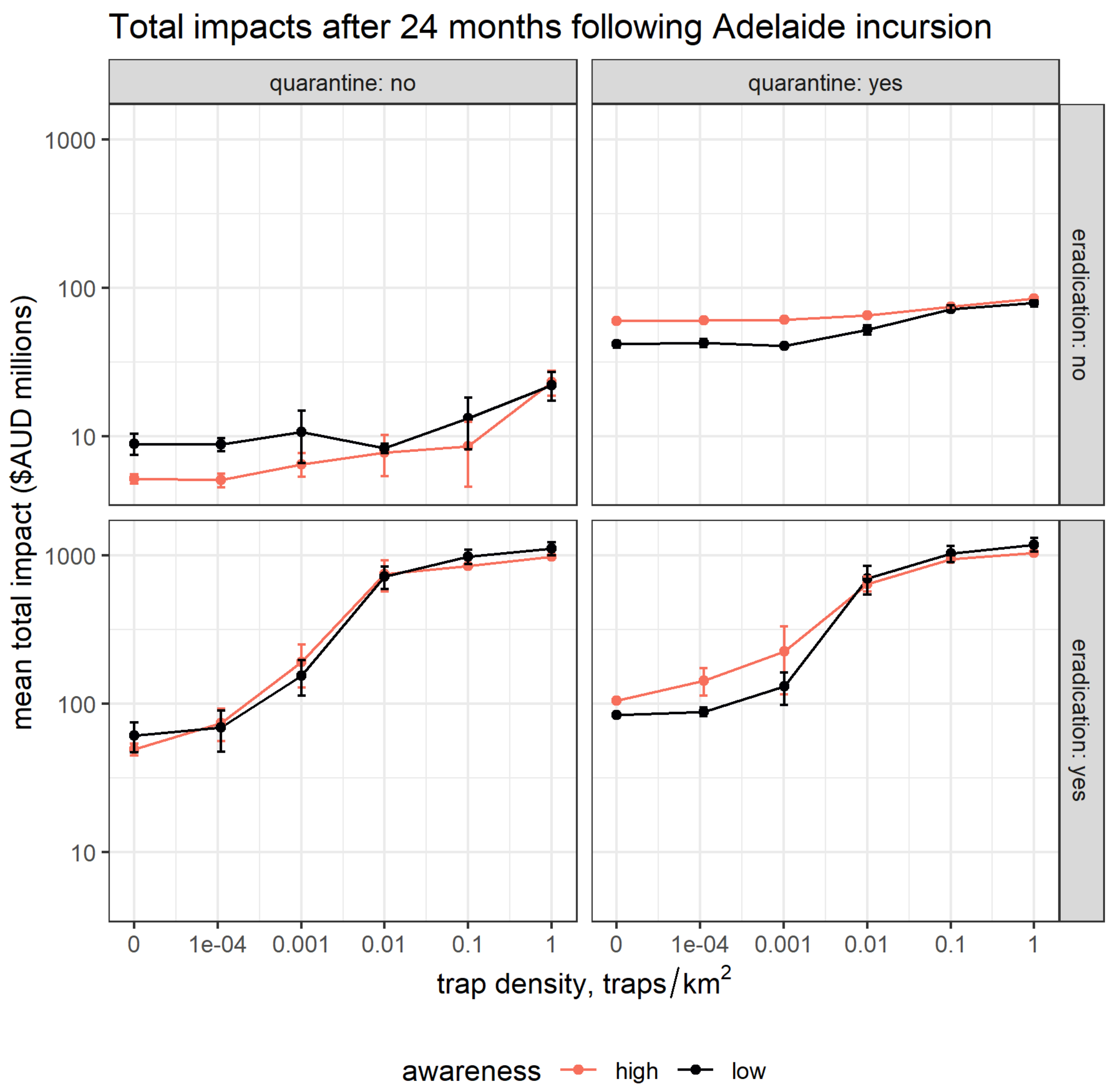
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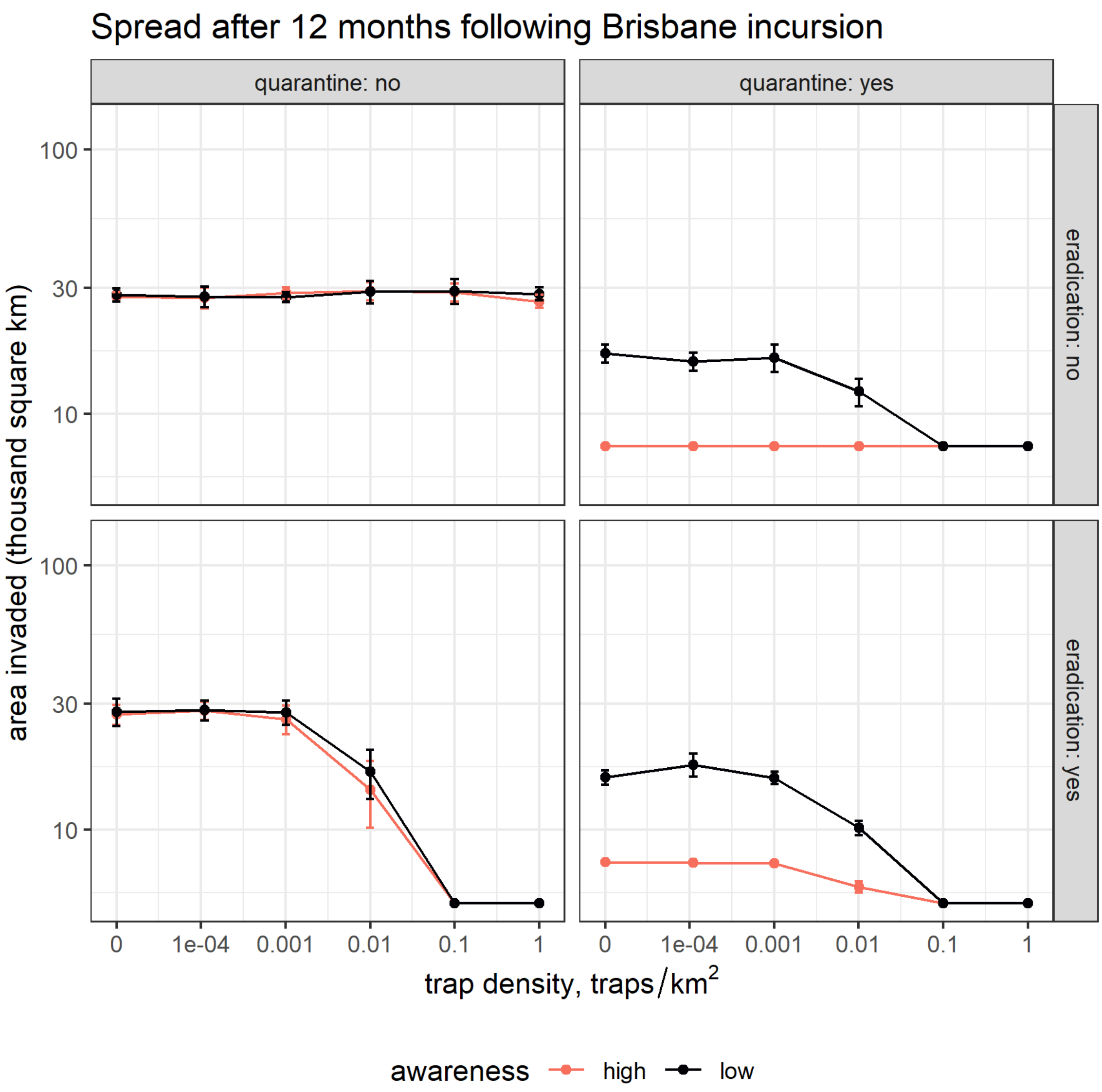
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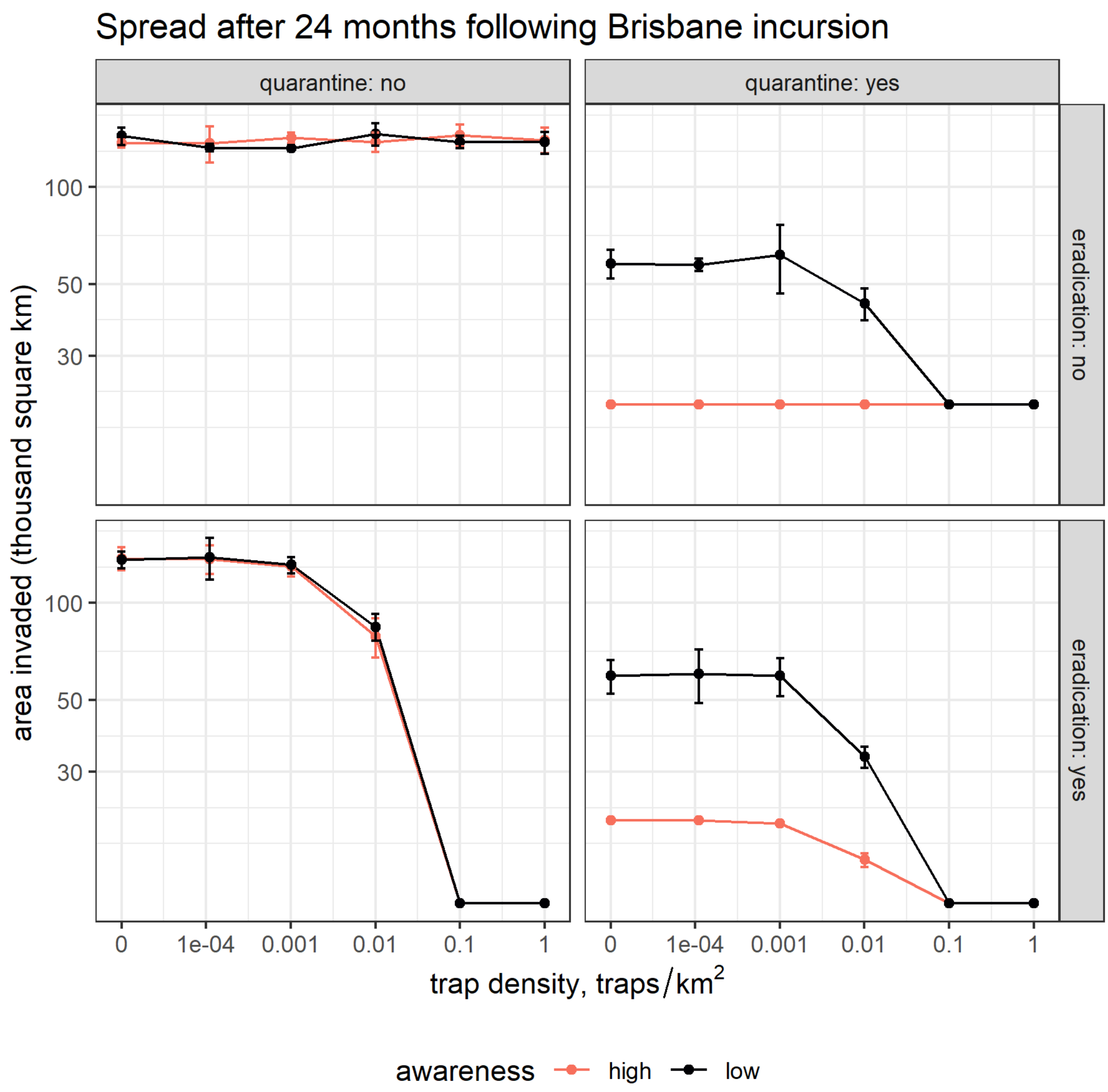
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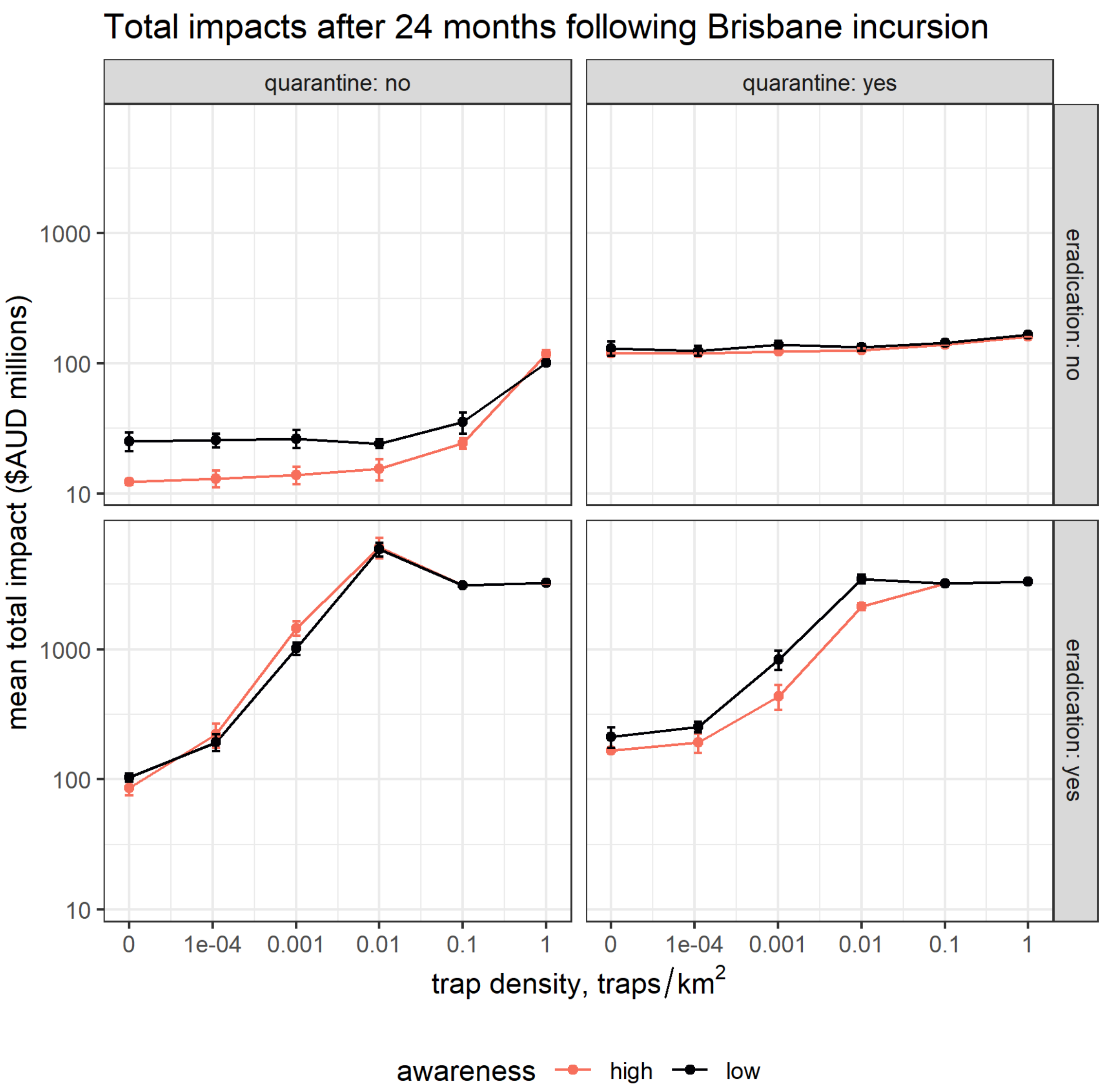
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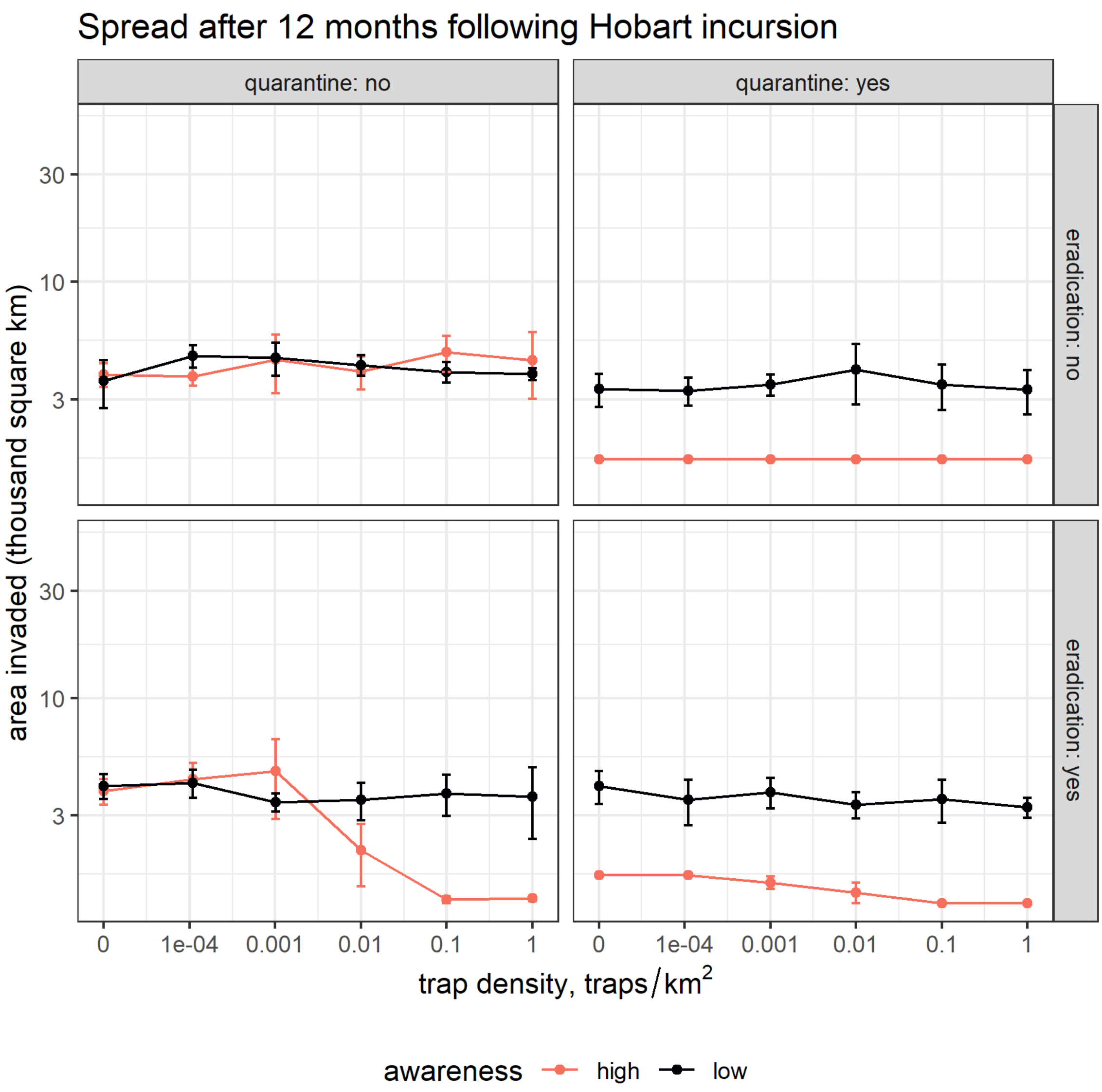
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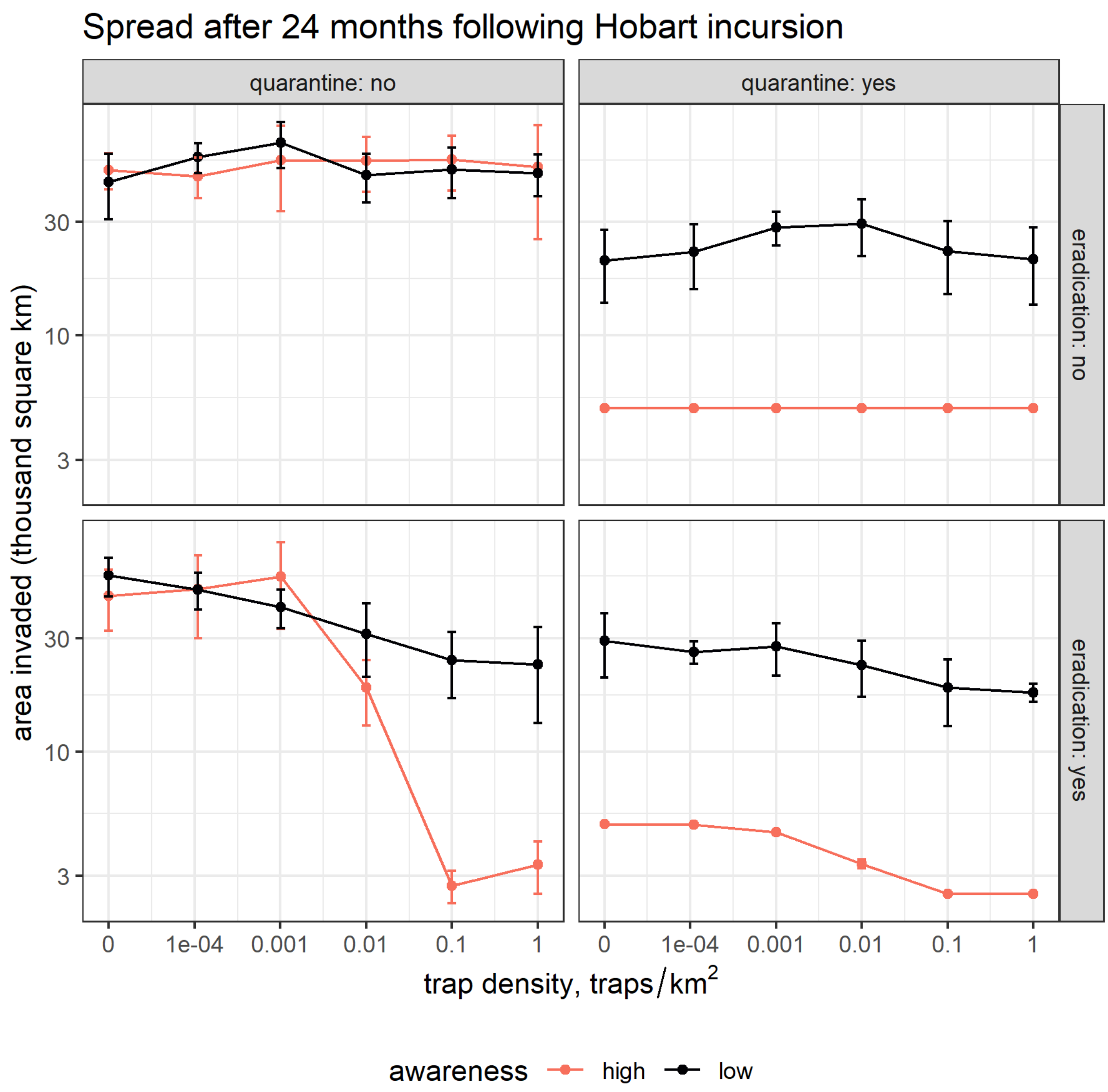
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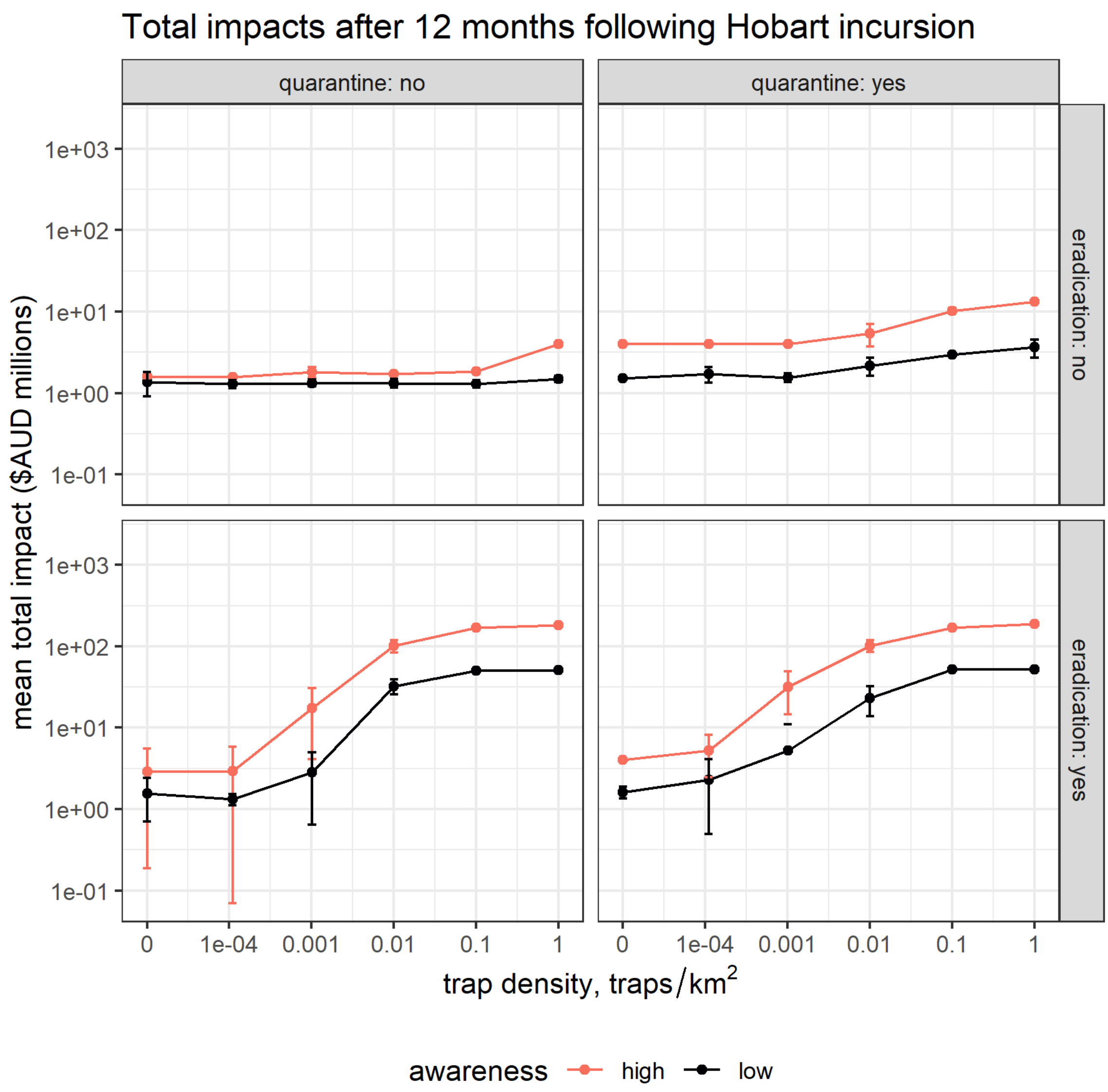
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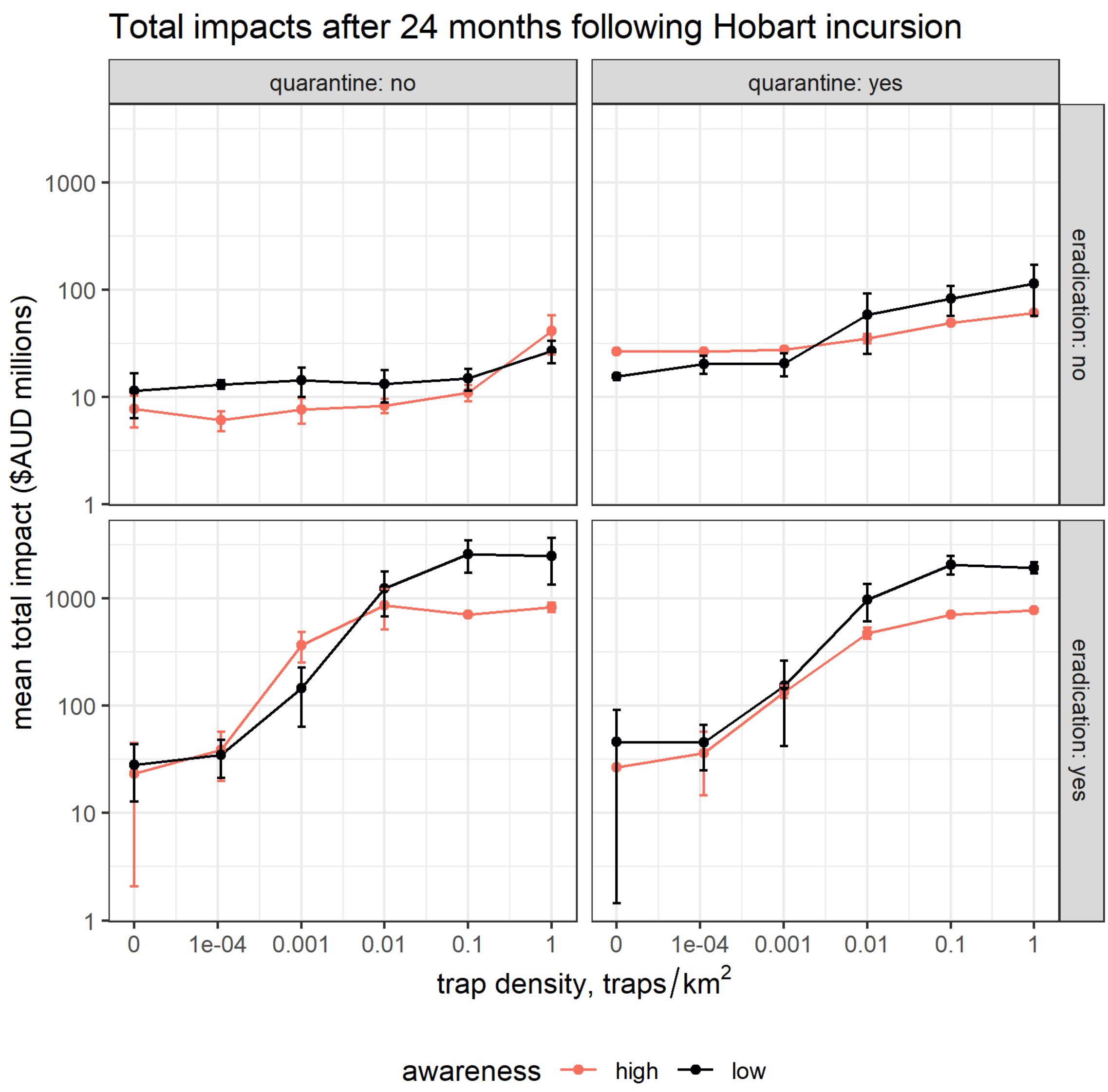

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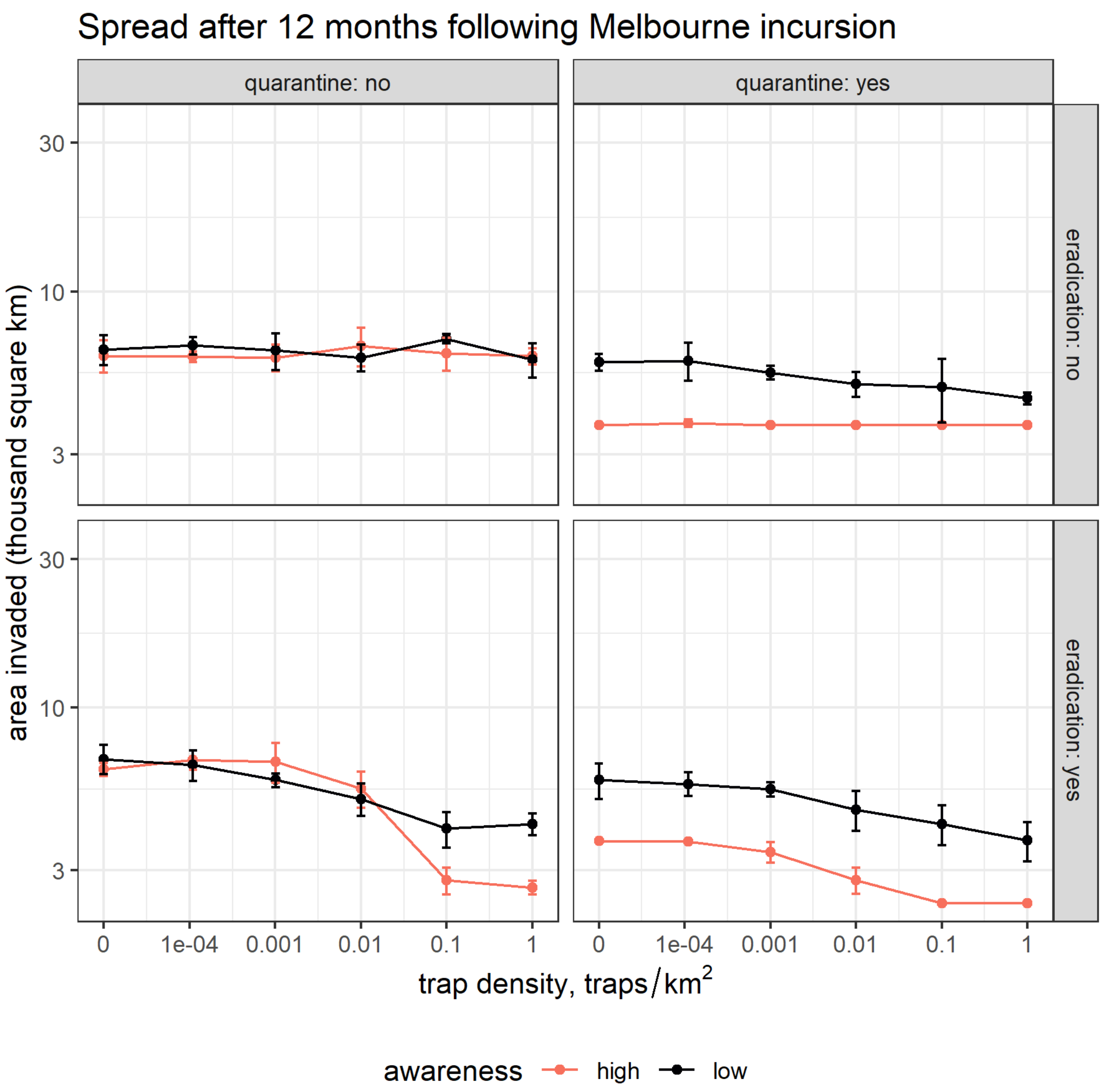
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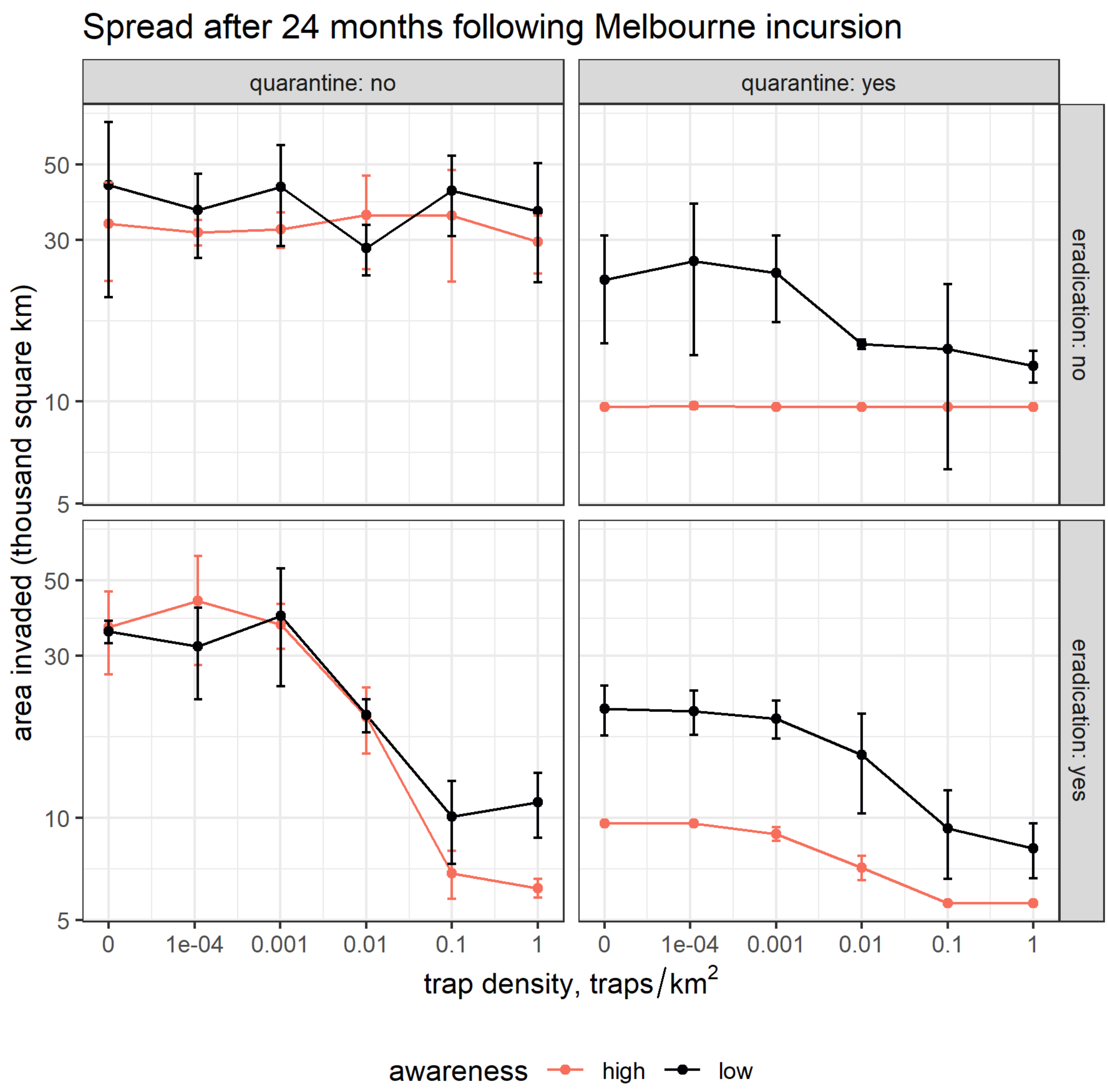
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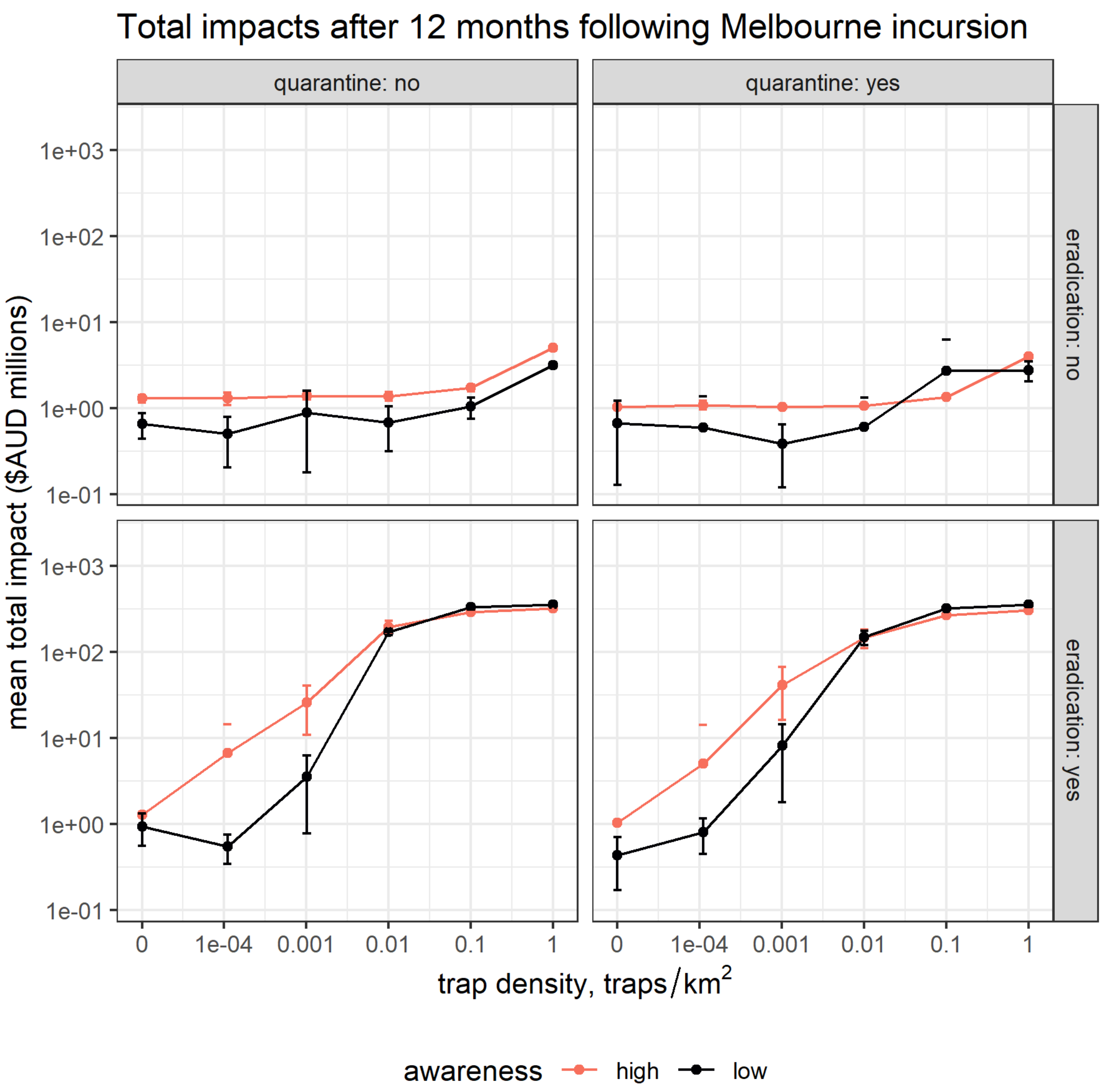
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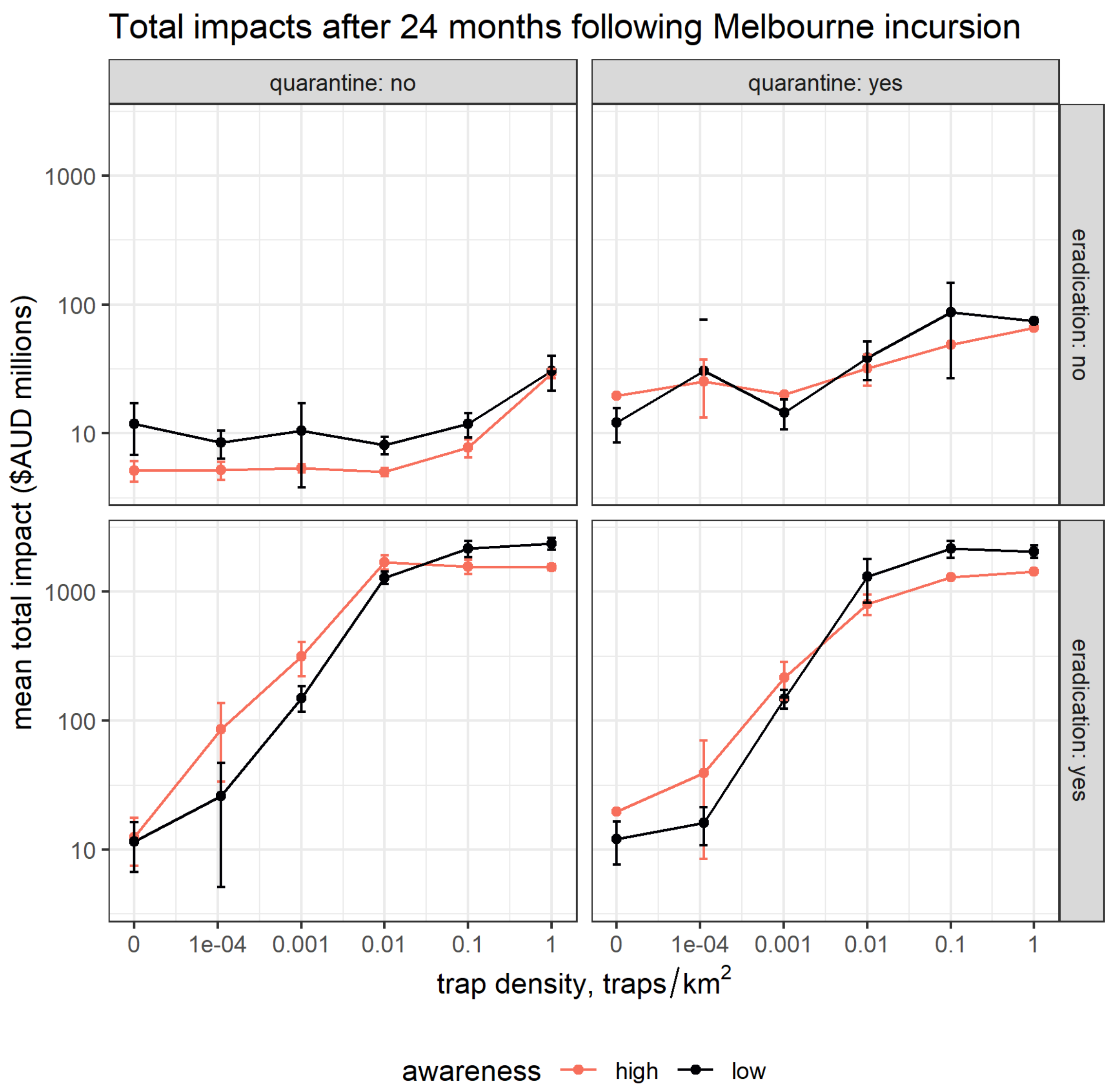
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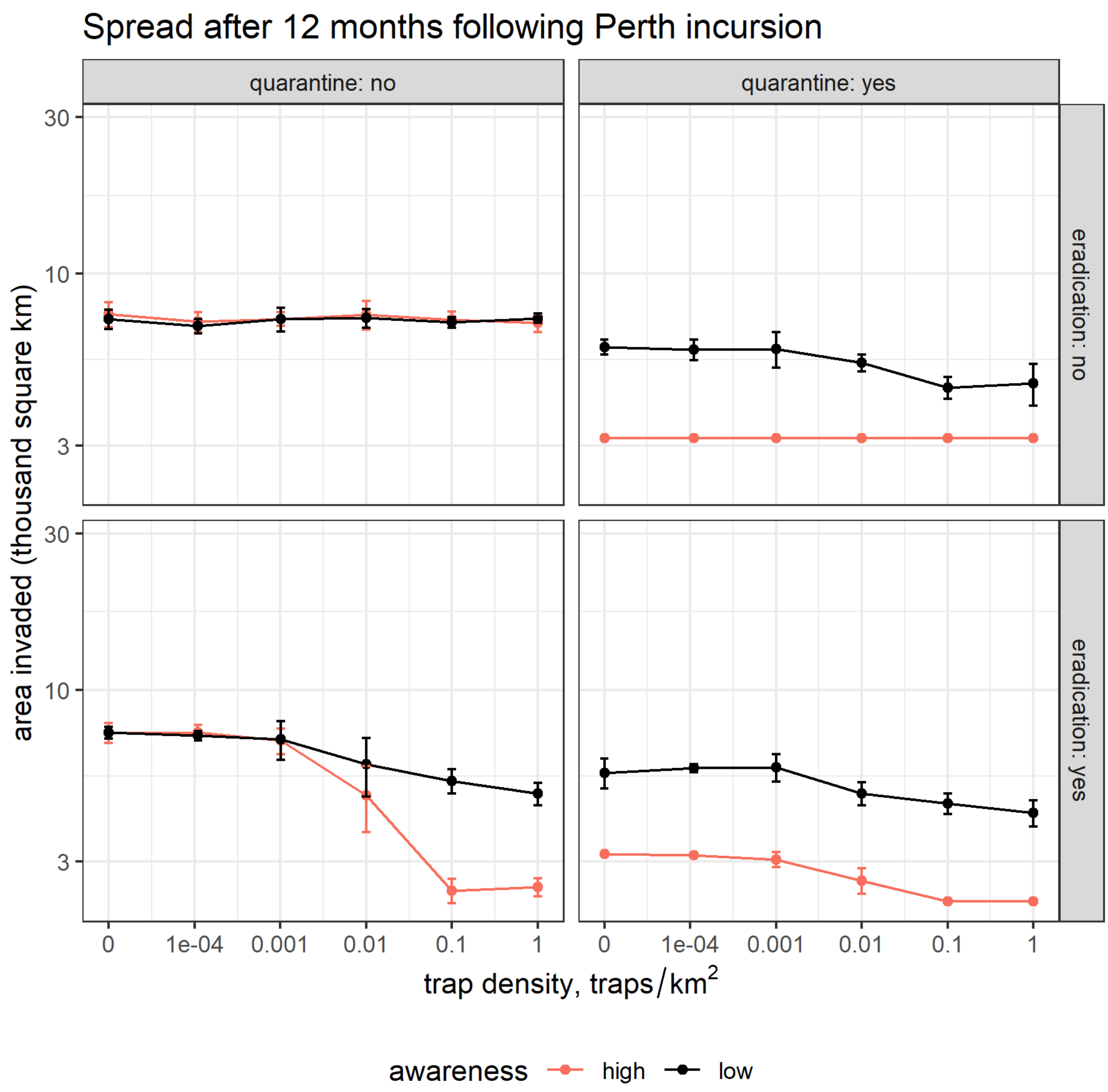
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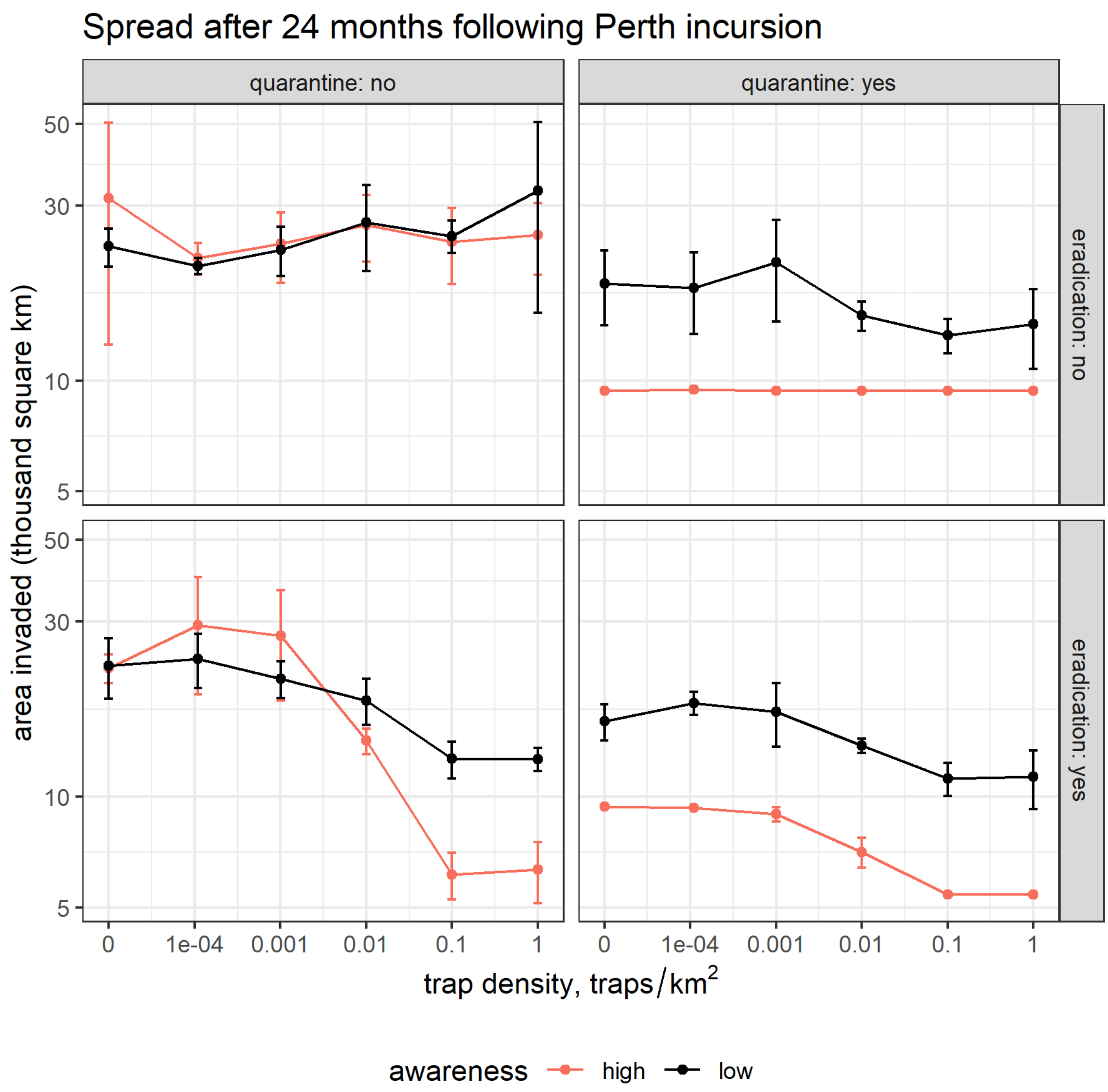
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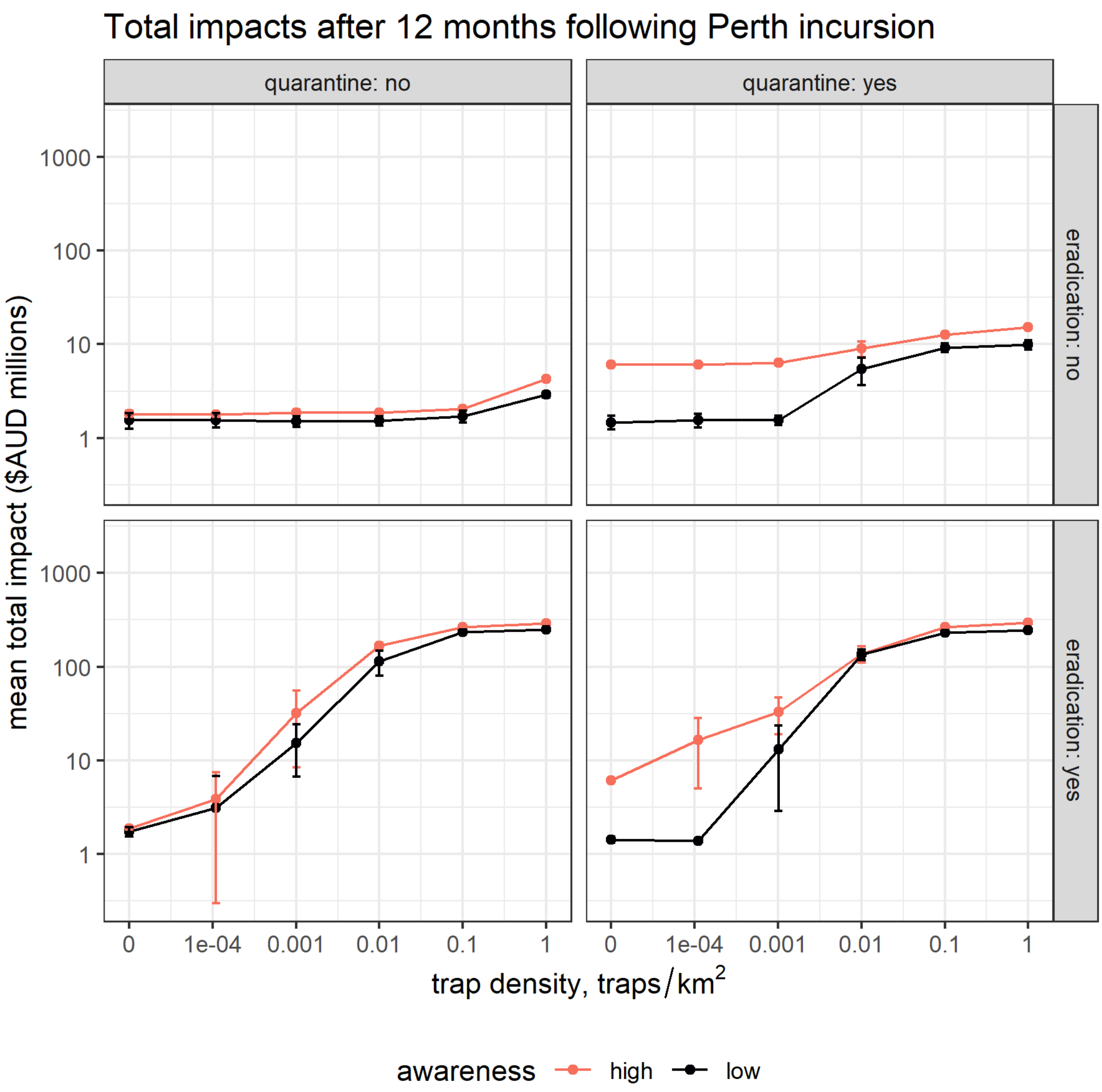
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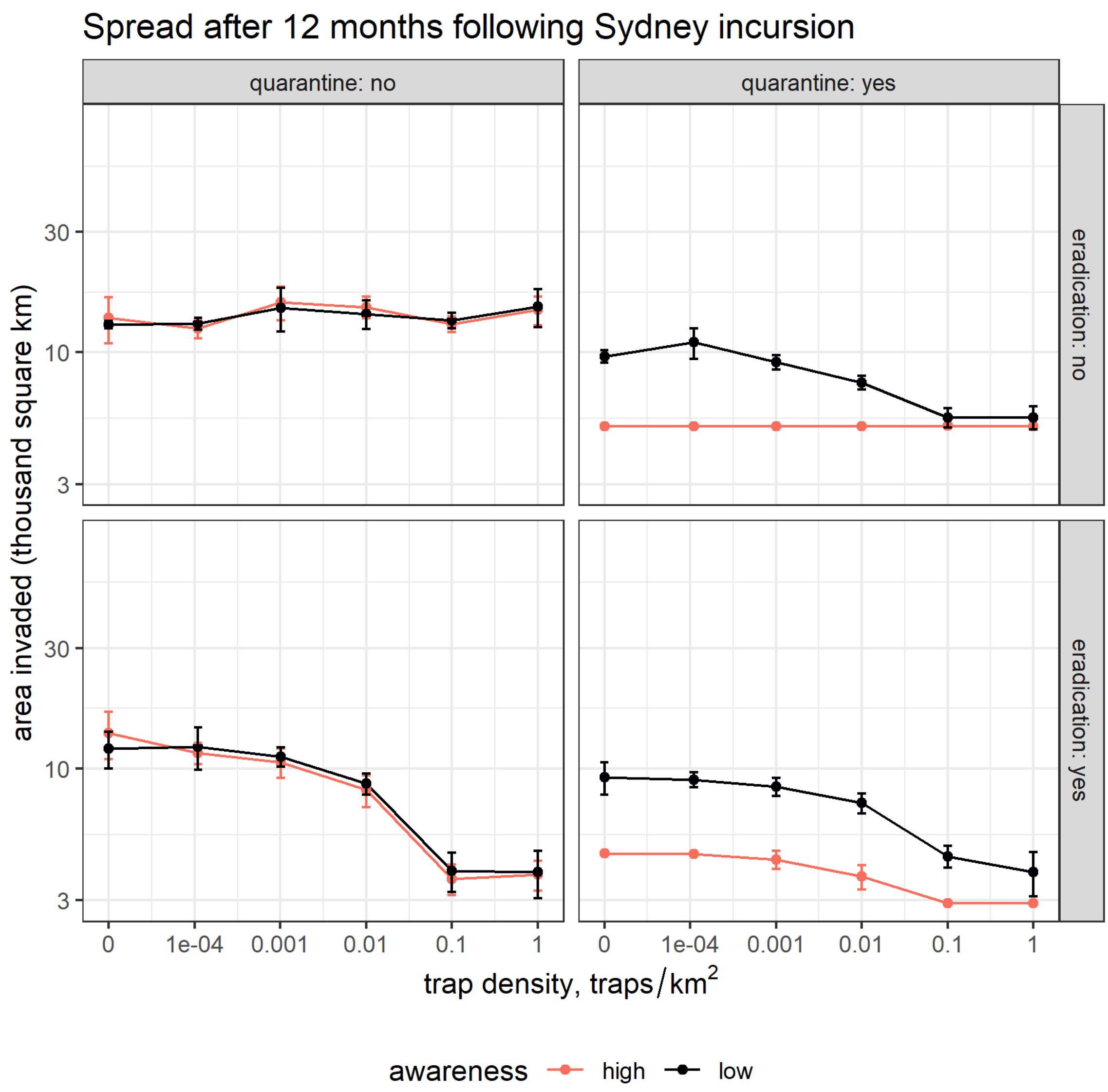
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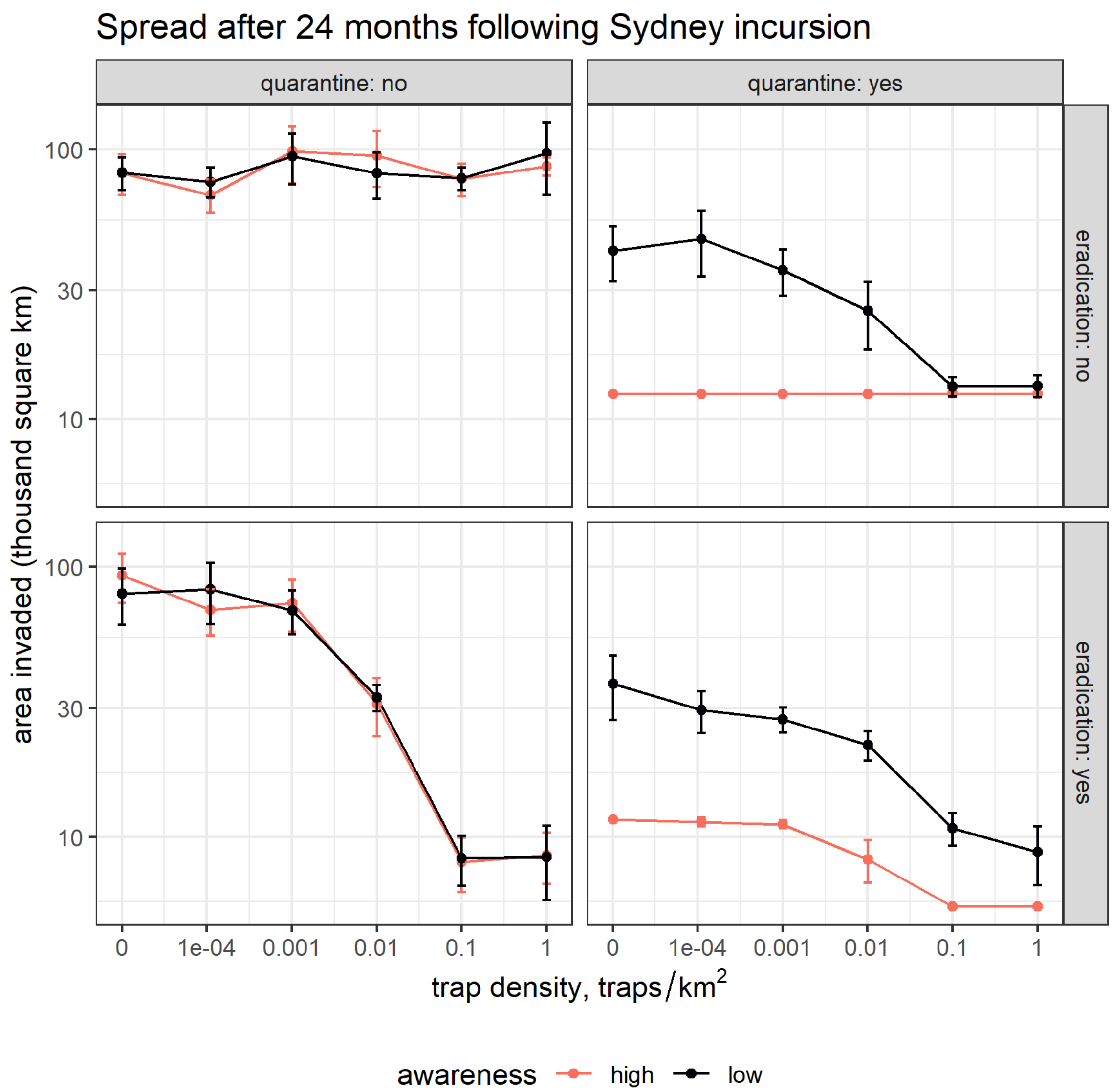
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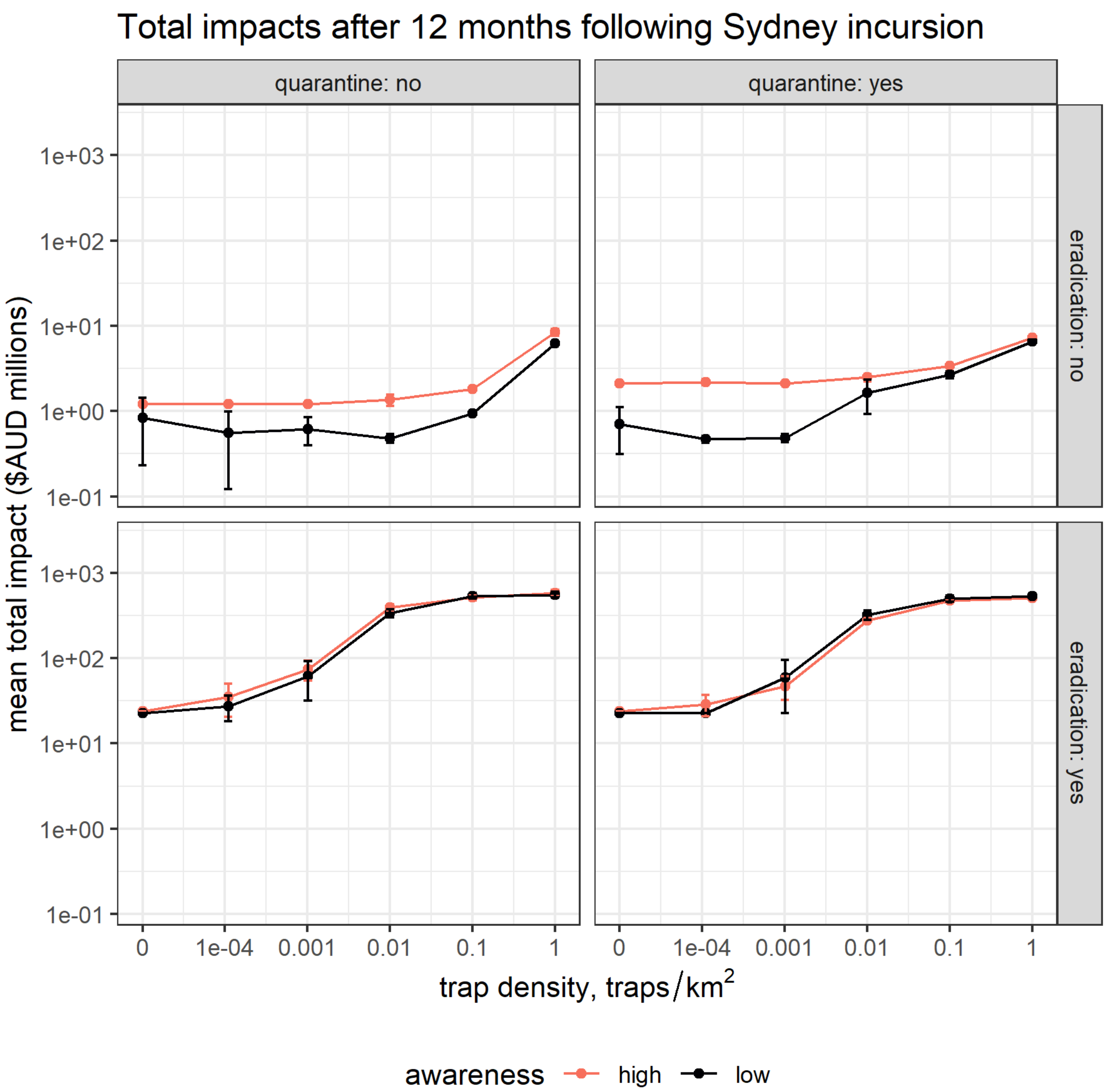
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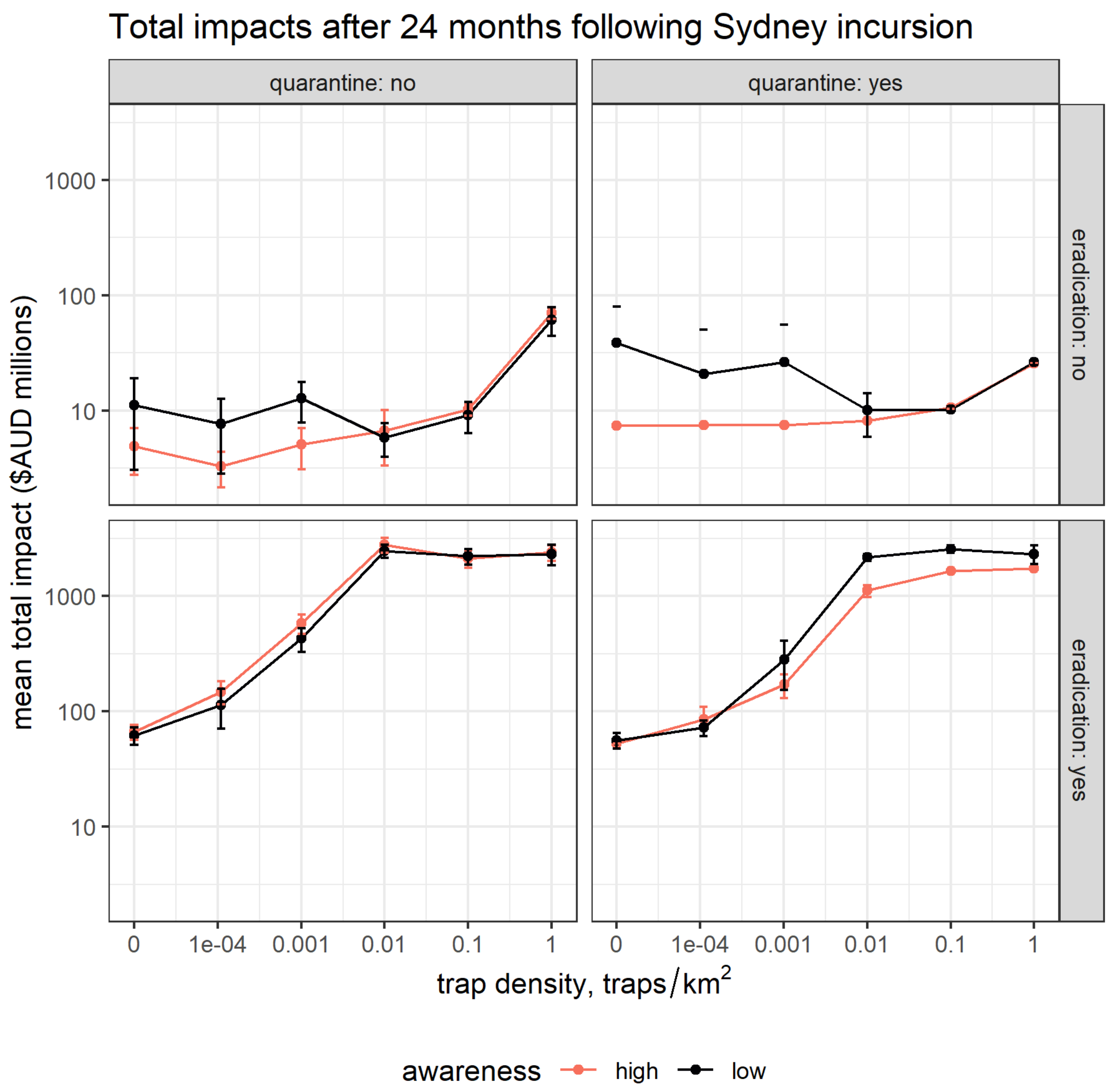
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trap density, traps/km2
awareness
high
low

Invasion history, biology, trapping for surveillance and control of *Drosophila suzukii*

Prepared by Plant and Food Research New Zealand (PFRNZ)

This report is part of Improving the biosecurity preparedness of Australian horticulture for the exotic Spotted Wing Drosophila (*Drosophila suzukii*) (MT17005). This project has been funded by Hort Innovation, using the strawberry, raspberry and blackberry, cherry and summerfruit research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not for profit research and development corporation for Australian horticulture.

Project partners

The spotted wing drosophila, SWD, *Drosophila suzukii*, poses a serious threat to many Australian and New Zealand horticultural industries. It has been defined as a 'Significant Threat' by NZ Wine, and it is on the Ministry for Primary Industries' (MPI) unwanted organism list. The damage and likely restricted market access that this pest could have would be wide ranging.

Unlike many other Drosophilidae that oviposit in fallen or rotting fruit, *D. suzukii* can oviposit in fresh fruit while still on the plant. To help prepare for this threat, we have engaged with international researchers and the literature (Table 1) to investigate invasion biology, monitoring and management tools.

Table 1. Search keywords used in addition to spotted wing drosophila and/or *Drosophila suzukii* to select literature for review. 452 publications were identified.

Incursion	Pathway	Fecundity	Release-recapture
Detection or first detection	Transport	Host preference	Attraction
Reported or first reported	Habitats or environments	Host suitability	Spatial
Establishment	Phenology	Dispersal/movement	Temporal
Invasion	Ovipositor	Lure	Model
Spread	Biology	Trap	Population
Distribution	Cold-tolerance	Odour or odor	Release-recapture

1. Introduction

Much can be learnt by reviewing previous incursions of a specific pest or pathogen. The information gleaned can assist with risk analysis and can aid readiness efforts for countries that consider the pest a threat. *Drosophila suzukii* has spread from its native range in Asia to over 30 countries in North America, South America and Europe (see Figure 1). The first incursions in each of these countries have been compiled (see section 2 and Table 2) and analysed to shed light on the type of sites where *D. suzukii* is likely to first arrive and then spread in Australia and New Zealand.

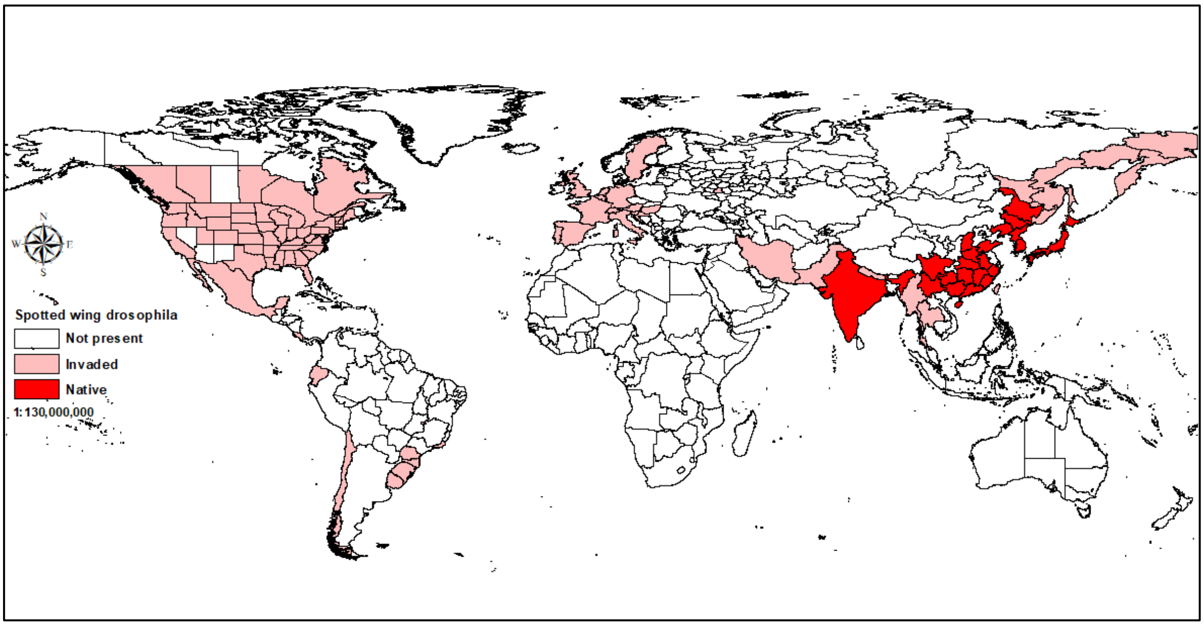

Figure 1. Global distribution of *Drosophila suzukii*
Source: Ministry for Primary Industries (https://www.mpi.govt.nz/protection-and-response/finding-and-reporting-pests-and-diseases/priority-pests-plant-aquatic/horticultural-pests/spotted-wing-drosophila/)

2. Drosophila *suzukii's* global incursion history

2.1 Origins - Asia

Little is known about the geographic origin of *Drosophila suzukii*. The insect thought to be native to Asia, including China, Japan and Korea (Walsh et al. 2011). The first report of *D. suzukii* is from Japan where maggots were found in pre-harvest cherries (*Prunus avium*) in 1916 in Yamanashi Prefecture, though *D. suzukii* was not described until 1931 (Asplen et al. 2015; MPI 2012). *Drosophila suzukii* is also reported from Taiwan, Pakistan, Myanmar, Nepal, Thailand, Far East Russia and India (Asplen et al. 2015; MPI 2012).

The first record of *D. suzukii* in the Middle East is from Iran in October 2015, where it was incidentally detected during an olive fruit fly survey. The specimens were found in protein-baited traps placed in olive groves on the slopes of the Elburz mountains (Parchami-Araghi et al. 2015).

2.2 North America

The first detection of *D. suzukii* in North America was confined to the Hawaiian Islands, but once it reached the continental mainland, spread was rapid. Significant damage has been seen in North America as population numbers have increased and range expansion has occurred. There are unconfirmed reports of *D. suzukii* in Costa Rica (Hauser 2011), however, these records remain dubious and should be treated with caution.

First detections

United States of America (USA)

In the USA there were essentially two 'first' detections, separated both geographically and temporally. *Drosophila suzukii* was recorded for the first time in North America in Hawaii on the island of Oahu in 1980. It was then reported on several other Hawaiian islands (Hauser 2011). The first detection on the mainland USA was in California in 2008, though the response to the detection was delayed somewhat due to mis-identification as *Drosophila biarmipes* Malloch (Hauser 2011). *Drosophila suzukii* larvae were found in raspberry crops and to a lesser degree in strawberry crops. Just one year later (in 2009) *D. suzukii* had spread to over 20 counties in California and was also found along the west coast in Oregon and Washington, and also in Florida. Public awareness and monitoring initiatives in 2010 resulted in finds of *D. suzukii* adults along the east coast (Hauser 2011).

Canada

In Canada, *D. suzukii* was first found in British Columbia in 2009. It was then detected in Alberta, Manitoba, Ontario and Quebec in 2010 (Asplen et al. 2015).

Mexico

Drosophila suzukii was first detected in Mexico in 2011 (Lee et al 2011) in Michoacán State. The pest rapidly expanded to other states, namely Colima, Guanajuato, Aguascalientes, State of Mexico, and Baja California (Lasa and Tadeo 2015).

2.3 Europe

The first point of detection in Europe is unclear. Some authors suggest Spain was the first location, others Italy, and some hypothesise that southern France was the likely spreading centre prior to 2008 (Cini et al. 2014). Regardless, *D. suzukii* is now present throughout much of Europe. Various monitoring programmes in the region seem to suggest population growth and spread occurred rapidly within countries, with the period from first detection to widespread occurrence spanning just a few years in many cases.

First detections

Spain

Drosophila suzukii was first detected in Spain in a pine forest in Rasquera in autumn 2008 (Calabria et al. 2012). Ten males and two females were collected from either fermented banana traps or fermented beer. Interestingly *D. suzukii* was not present in samples collected from the south at the same time, nor was it present in samples collected from Barcelona the previous year (2007) (Calabria et al. 2012). In 2011 *D. suzukii* was found in traps in fruit crops, and apparently also at a wholesale fruit market (Asplen et al. 2015). By 2013 the pest was found in cherry orchards in north western Spain in areas that had been sampled since 2010 (Asplen et al. 2015).

Italy

Traps deployed in Tuscany in 2008 caught the first *D. suzukii* specimens in Italy (Cini et al. 2012). The pest was first reported in 2009, however, when the catches from the 2008 traps were inspected, *D. suzukii* was found (Asplen et al. 2015). Oviposition was observed on blueberry, strawberry and blackberry.

France

In late August/early September of 2009 *D. suzukii* was first detected in France in Montpellier and Alpes Maritimes, however, it was absent from samples collected in the north (Calabria et al. 2012).

Slovenia

The first find of *D. suzukii* in Slovenia was reported in October 2010 (Seljak 2011).

Croatia

Drosophila suzukii was first found in Croatia in apple cider vinegar-baited traps in a peach orchard in the Dalmatia region in 2010. Monitoring in 2013 confirmed that the pest was present and widespread. It has been detected in urban areas and horticultural crops in coastal areas, inland and on two islands (Bjelis et al. 2015).

Germany

The first German detection of *D. suzukii* was in September 2011, despite monitoring the previous year (Asplen et al. 2015; Vogt et al. 2012). Larval infestations were found in cherries, raspberries, blackberries, elderberries, and grapes (Vogt 2014). High numbers of adults were captured post-harvest in both orchards and in wild areas (Asplen et al. 2015; Briem et al. 2015).

Belgium

D. suzukii was first reported in Ostend, Belgium (4 m above sea level) in September 2011. A single male was captured near the harbour in Zerbrugge (Mortelmans et al. 2012). The pest was detected again in 2012 in cherries, plums, strawberries, raspberries, and blueberries (Asplen et al. 2015).

Austria

The first report of *D. suzukii* in Austria occurred in September 2011. The pest was found in three states infesting raspberries, elderberries, and hardy kiwi (kiwiberries). Nationwide monitoring in 2012 found that *D. suzukii* was concentrated in the west and south of the country, but by 2013 it was shown that *D. suzukii* was distributed throughout Austria (Asplen et al. 2015).

Switzerland

Drosophila suzukii was first confirmed in Switzerland in July 2011. Monitoring using apple cider vinegar baited traps found that *D. suzukii* was present throughout the country, from fruit production areas at low altitude to the bush line. Pest pressure in Switzerland has been observed to increase through the season from May to November (Asplen et al. 2015).

Netherlands

A *D. suzukii*-specific survey conducted in the Netherlands in 2012 detected the pest at eight locations, including forested sites. The survey utilised traps baited with apple cider vinegar and red wine. Monitoring in 2013 did not detect *D. suzukii* until mid-August, with the first trap captures in cherry orchards near a sales point for imported fruit. High rates of infestation have been seen in elderberry (*Sambucus* spp.) crops in the Netherlands (Asplen et al. 2015; Helsen et al. 2013).

United Kingdom

The first report of *D. suzukii* in the United Kingdom was in September 2012 (Asplen et al. 2015; EPPO 2012b). A national monitoring programme deployed the following year in soft and stone fruit orchards in England and Scotland detected *D. suzukii* in August, with captures increasing through late autumn and winter. More *D. suzukii* were trapped in woodland compared to crops (Asplen et al. 2015).

Hungary

The first detection in Hungary was unusual – in September 2012 *D. suzukii* was detected at a highway rest stop (Kiss et al. 2013; Lengyel et al. 2015). The detection was the result of a nation-wide invasive pest survey which involved placement of bottle traps containing apple cider vinegar along highways (Kiss et al. 2013). A countrywide trapping programme for *D. suzukii* followed, focussing on highway rest areas and commercial orchards. *D. suzukii* was found in five locations along highways, but was not detected in rural orchards (Lengyel et al. 2015). Subsequent surveys indicated that *D. suzukii* had become relatively widespread in Hungary by the end of 2014, with damage reported in raspberry, plum and nectarine orchards (Kiss et al. 2016).

Portugal

Drosophila suzukii was first identified in July 2012 in Portugal in Odemira and Algarve in the westernmost part of the Iberian Peninsula (Asplen et al. 2015). The detection was in a commercial raspberry greenhouse (EPPO 2012a).

Bosnia and Herzegovina

D. suzukii was recorded at several locations in Bosnia and Herzegovina in 2013 (Asplen et al. 2015; Ostojic et al. 2014).

Montenegro

D. suzukii was found in 2013 along the coast and in the Podgorica area of Montenegro in Tephri traps (Asplen et al. 2015; Radonjic and Hrncic 2015).

Romania

The first Romanian detection of *D. suzukii* occurred in Bucharest was in 2013. Tephri traps (attractant not stated) set in wild blackberry as part of a national fruit fly trapping programme captured adult *D. suzukii* (Asplen et al. 2015; Chireceanu et al. 2015).

Serbia

A survey of fruit conducted in October and November 2014 revealed *D. suzukii* in four districts in Serbia. The pest was present in raspberry, blackberry, fig and grape and populations were established at altitudes from 70-800m (Toševski et al. 2014).

Sweden

The first record of *D. suzukii* in the Nordic region is from the county of Scania (Skåne) in southern Sweden where it was detected in August 2014 (Manduric 2017). The specimens were found in apple cider vinegar-wine- baited traps that had been placed in mixed shrubby vegetation near grocery stores in an urban area. *D. suzukii* was also in two berry plantations later that same year less than 50km from the initial find (Manduric 2017). Inventory work in crops in 2015 found further flies in Scania county, but they were absent from other regions. However, *D. suzukii* was found in three additional regions in 2016 in raspberries, blackberries, blueberries, strawberries, elderberries, red currants, cherries, plums and grapes (Manduric 2017).

Ukraine

Specimens of *D. suzukii* were initially found in Ukraine near Yalta, an important port on the Black Sea, during biodiversity surveys that used smashed fermented apples and wheat beer as lures in 2014 and 2015.The same sampling localities had been surveyed for *Drosophila* species every year since 2005 (Lavrinienko et al. 2017).

Turkey

In Turkey *D. suzukii* was first collected from infested strawberry plants from the garden of the Department of Horticulture at Atatürk University in Erzurum (Orhan et al. 2016). The damaged strawberry crops were observed on September 2014 and samples were taken into the lab to rear out the larvae, which were subsequently identified as *D. suzukii* (Orhan et al. 2016).

Poland

Drosophila suzukii was first detected in Poland at the end of 2014, despite active searching for the pest in the years prior. Fruit monitoring was conducted in plantations (e.g. blueberries) in 2012 and 2013 and observations were carried out at a wholesale market in Bronisze near Warsaw where domestic and imported fruit is stored and traded, *D. suzukii* was not detected. When adults were finally detected in 2014, they were captured in blueberries in the west and raspberries in the south (Asplen et al. 2015).

Greece

In 2013, *D. suzukii* was reported in the Ioannina region of Greece, but this initial detection of an adult male in a mixed berry orchard trap remained unconfirmed (Asplen et al. 2015). This initial report was followed by a detection on Crete in March 2014, where five *D. suzukii* specimens were caught in a beer trap in a shrub in a low scrubland area (Asplen et al. 2015; Máca et al. 2015).

Bulgaria

Drosophila suzukii first appeared in Southwestern Bulgaria in September 2014. The pest was detected via trapping (lure not stated) close to cherry trees (Asplen et al. 2015; EPPO 2015a).

Czech Republic

Drosophila suzukii was first confirmed in the Czech Republic in fruit production areas in September 2014. The detections were the result of trapping efforts with apple cider vinegar-baited traps (Asplen et al. 2015; EPPO 2014a).

Slovakia
The pest was first found in October 2014 in Slovakia in a trap (likely apple cider vinegar) at a farm in Levice District. The site had apple and plum trees present and grapes were processed there, though no damage was observed (Asplen et al. 2015; EPPO 2014b).

Ireland
The first detection of *D. suzukii* in Ireland was in August 2015 in a trap located by the packing house on a Dublin farm. The pest was trapped in hedgerows surrounding a soft fruit and stone fruit growing area in the weeks following the initial detection (EPPO 2015b).
While the use of a pheromone trap was indicated in the report, no further evidence of a pheromone trap for the detection of adult *D. suzukii* has been found. This is likely the incorrect use of the word pheromone. Local authorities recommend the use of "vinegar based pheromone traps".

Cyprus
Traps (lure not stated) placed in commercial crops in Nicosia district caught the first *D. suzukii* specimens in Cyprus I 2017 (EPPO 2017a).

2.4 South America

South America is the latest continent to have been invaded by *D. suzukii*, with the first validated detection in 2013. A number of South American countries currently only have localised populations, rather than the widespread distribution seen in many European and North American countries. There are unconfirmed reports of *D. suzukii* in Ecuador (Hauser 2011).

First detections

Brazil
The first occurrence of *D. suzukii* in Brazil was recorded in Santa Catarina state in February 2013. Samples were collected with banana-baited traps in nearby regions through to May (Deprá et al. 2014). *Drosophila suzukii* has primarily been reported in coastal states in Brazil - in 2014, *D. suzukii* had only been collected from regions <400km from the coast (Deprá et al. 2014). *Drosophila suzukii* has since spread to numerous other states and is has been confirmed as present in the highlands of Espírito Santo (Zanuncio-Junior et al. 2018). The pest is associated with blackberry and sometimes papaya and strawberry (Zanuncio-Junior et al. 2018). Human mediated spread has been documented in Brazil – in 2014 researchers purchased fruit from a Sao Paulo grocery store and reared *D. suzukii* from blueberries which had been produced in a different state (Santa Catarina) (Vilela and Mori 2014).

Uruguay
Banana-baited traps and over-ripe or damaged blueberries collected from the ground revealed *D. suzukii* for the first time in Uruguay in 2013 (EPPO 2016; González et al. 2015).

Argentina

One of the more recent countries to be invaded by *D. suzukii* is Argentina. It appears that the pest was first detected in Buenos Aires province in 2015 (Lavagnino et al. 2018). It is now present in the Mesopotamia region, Tucumán and Patagonia region, which constitutes the southernmost record of *D. suzukii* in South America. Flies in Argentina have been captured near orange, mulberry and raspberry plantations, as well as from an unknown host which may be the native Opuntia cactus (Lavagnino et al. 2018).

Chile

In a paper published in 2015 *D. suzukii* was reported near the principle port of Valparaíso (Medina-Muñoz et al. 2015), however, the identification was shown to be incorrect and as such the record was denied by the Chilean NPPO. The first confirmed report of *D. suzukii* in Chile was in 2017. Traps paced in blackberry bushes caught specimens in La Araucanía region, near an international road which leads to a border point (EPPO 2017b). Since the initial detection *D. suzukii* has been caught in Los Lagos and Los Ríos regions.

Table 2. First detections of *Drosophila suzukii* in countries in Europe and the Americas* ordered chronologically for each region.

Country	**Date**	**Vegetation observations**	**Means of detection**	**Prior trapping?**	**Land use**	**Reference**
North America and central America						
USA - Hawaii	1980					Hauser 2011
USA-mainland	2008	Raspberry Strawberry	Crop scout submission		Production area	Hauser, 2011
Canada	2009					Asplen et al 2015
Mexico	2011					Lee et al 2011
Europe						
Spain	2008	pine forest	Trapping	Yes in 2007	Wilderness area	Calabria et al 2012
Italy	2008	Raspberries	Malaise traps			Cini et al 2012, EPPO 2010
France	2009	Cherry and Strawberry				Calabria et al 2010, EPPO 2010
Slovenia	2010					Seljak 2011
Croatia	2010	Raspberry, peach and grapevine	Trapping		Production area	Bjelis et al 2015
Germany	2011		Trapping	Yes in 2010		Vogt et al. 2012; Asplen et al 2015

Belgium	2011				private garden	Mortelmans et al. 2012, EPPO 2011
Austria	2011					Asplen et al 2015
Switzerland	2011	Strawberry, raspberries, blueberries and cherry orchards	Trapping (apple cider vinegar)		Production area	EPPO 2011
Portugal	2012	raspberries			Commercial greenhouse	Asplen et al 2015; EPPO 2012
Netherlands	2012		Trapping (apple cider vinegar and wine)		Wilderness areas and private gardens	Helsen et al. 2013; Asplen et al 2015
United Kingdom	2012	Raspberry and blackberry			Research plots	EPPO 2012; Asplen et al 2015
Hungary	2012		Bottle traps (apple cider vinegar)		Highway rest stop	Lengyel et al 2015
Bosnia and Herzegovina	2013					Ostojic et al. 2014; Asplen et al 2015
Montenegro	2013		Trapping			Radonjic and Hrncic 2015; Asplen et al 2015
Romania	2013	blackberry	Tephri traps		wilderness	Chireceanu et al 2015; Asplen et al 2015
Serbia	2014	raspberry, blackberry, fig and grape	Fruit survey			Tosevski et al. 2014
Sweden	2014		Trapping		Urban (commercial)	Manduric 2017
Ukraine	2014			Yes, since 2005		Lavrinienko et al 2017
Turkey	2014	Strawberry	Crop observation		Research plots	Orhan et al 2016

Poland	2014	Blueberry and raspberry		Yes, 2012 and 2013	Production area	Asplen et al 2015
Greece	2014	Native vegetation	Trapping (beer)		Wilderness area	Maca 2014; Asplen et al 2015
Bulgaria	2014	Cherries	Trapping	Yes, since 2012	Production area	EPPO 2015; Asplen et al 2015
Czech Republic	2014	Fruit	Trapping (apple cider vinegar)		Production area	EPPO 2014; Asplen et al 2015
Slovakia	2014	Apple and plum	Trapping		Production area	EPPO 2014; Asplen et al 2015
Ireland	2015		Trapping		Production area	EPPO 2015
Cyprus	2016		Trapping		Production area	EPPO 2017
South America						
Brazil	2013		Trapping (banana)			Depra et al 2014; Vileia and Mori 2014
Uruguay	2013	Blueberry	Trapping, fruit surveys			Gonzales et al 2015; EPPO 2016
Argentina	2015					Lavagnino et al 2018
Chile	2017	Blackberry	Trapping			EPPO 2017

*NB: It is very probable that the history of first reports presented above has been influenced by monitoring sites and sampling effort rather than the true incursion epicentre. It is also important to note that although the table above sets out ‘first detections’ in many different countries, it is very possible that they are not new introductions at all, rather overland spread of the population throughout each continent.

3. What can be learnt from prior incursions?

When the first detections around the world are viewed in aggregate, a number of commonalities can be seen that may help Australia and New Zealand consider pathways and possible sites of first arrival and detection.

3.1 Pathways

Spread to new continents

For a pest to spread to new continents as *D. suzukii* has, the insect needs to travel over significant ocean barriers and establish in an entirely new region. Many authors have suggested that the key means of spread for *D. suzukii* is likely to be human mediated transport of infected fruit (Calabria et al 2012, Mortelmans et al 2012; Cini et al 2014; Asplen et al 2015). This concept is supported by the rearing of *D. suzukii* from domestic retail blueberries purchased from a grocery store in Brazil (Vileia and Mori 2014). There have been numerous first detections near important sea ports, for example Zerbrugge in Belgium (Mortelmans et al. 2012) and Yalta in Ukraine which is a major tourism and commercial port (Lavrinienko et al 2017). These detections near ports may be a coincidence, or may indicate that there is a higher risk of entry and establishment near sea ports. There have also been first detections near facilities where imported fruit arrives or is sold from, for example the detection near a grocery store in Sweden (Manduric 2017), by an imported fruit sales point in the Netherlands (Helsen et al. 2013) and in trees near shops and restaurants in tourist areas in Croatia (Bjelis et al 2015). The above examples from previous incursions support the idea that movement of infested fruit (commercial or otherwise) is the most probable pathway for long-distance movement to new continents, whether by air or sea.

The number of introduction events in Europe is unknown. Genetic analysis has shown that all of the first Serbian *D. suzukii* specimens shared the same COI haplotype with specimens collected from Spain, Portugal, Italy and Japan (Lavrinienko et al 2017). However, another Serbian specimen was sequenced after the initial report and this was found to share its COI haplotype with specimens from the USA and China. The genetic analysis indicates that there may have been multiple invasions of *D. suzukii* into Europe (Lavrinienko et al 2017).

Localised spread and reproduction

In 2010 it was estimated by Pratique (2010) that it would take 5 to 10 years for the pest to reach its maximum extent in the EPPO area (Europe and the Mediterranean) (MPI 2012). The spread across the European continent has indeed been rapid and parallels what was observed in North America (Burrack et al. 2012). Lengyel et al. (2015) estimated spread to be around 320–390 km year, while Calabria et al. (2012) estimated that *D. suzukii* was able to spread approximately 1400 km a year.

The relatively high spread rate of *D.* suzukii supports the concept of vehicles as a key means of transport for medium-distance movement within continents and countries. The Hungarian example suggests that transport along highways could have been a key means of spread for *D. suzukii*. Traps at highway rest areas were positive for *D. suzukii* from the survey outset, while many other traps around the country remained negative. In addition, there were no orchards near the detection site, supporting the hypothesis that the flies arrived by transport along the highway rather than making their own way from surrounding habitat (Lengyel et al. 2015). This does not preclude other means of human-mediated spread, for example transport by air, rail or sea, nor does it rule out natural spread, with the flies gradually expanding their geographic range in a country or continent without human intervention (i.e. by adult flight or being blown by the wind).

One of the most alarming attributes of *D. suzukii* is its ability to invade a region quickly. This is largely due to its high reproductive rates, relatively long life, broad host range, and capacity to survive in both cool and warm areas. Laboratory studies have shown that *D. suzukii* has a growth rate allowing a population to double in size in as little as four days (Emiljanowicz et al. 2014). While this is, indeed, alarming, it likely is an overestimation due to ideal rearing conditions.

In Japan (on cherries), SWD has been shown to undergo 13 generations/yr (Kanzawa 1939). While having cooler winters in Japan, the cherry growing season climate there is quite similar to that found in New Zealand's sweet cherry orchard regions during the growing season. Oviposition rates for SWD can exceed 25 eggs/day/female, depending on temperature (Kinjo et al. 2014). Higher temperatures (above 28 °C) had a significant impact on both mating and developmental success and might explain frequent gaps in field population monitoring during peak summer times.

When compared to commercial blueberries, the highest net reproductive rate and intrinsic rate of population increase for SWD was recorded at 22 °C on sweet cherry (Tochen et al. 2014) (Table 3). Of greatest concern, however, is that in moderate or mild agricultural regions where *D. suzukii* populations have been established, it can be found in all life stages year round (Dalton et al. 2011), suggesting that SWD is capable of cycling through – egg to adult – in environments that provide both continuous access to hosts and mild temperatures.

Table 3 Parameters of temperatures where population increase for *D. suzukii* was measured on cherry and blueberry (from Tochen et al 2014).

Temperature (°C)	Developmental and reproductive parameters					
	R_o		T		r_m	
	Cherry	Blueberry	Cherry	Blueberry	Cherry	Blueberry
14	8.1	7.0	43.9	39	0.05	0.05
18	140.8	33	39	28.3	0.13	0.12
22	195.1	79.1	24.2	25.1	0.22	0.17
26	13.4	17.2	12.5	13.9	0.21	0.2
28	2.1	0.6	12.7	12	0.02	0.01

R_o, the net reproductive rate; T, mean generation time in days; r_m, intrinsic rate of population increase.

Ultimately, the realized fecundity of SWD will depend upon several factors, including temperature, host quality, duration of warm and cold seasons, and SWD population densities (Bellamy et al. 2013; Guédot et al. 2018; Hamby et al. 2016; Wiman et al. 2014).

It is interesting to note that despite its world-renown reputation for causing economic damage in soft fruits, no country has been able to limit SWD population growth once established (Asplen et al. 2015), regardless of the honest efforts by those countries to do so. The rapid spread of SWD across both North America and Europe (and currently Chile), for example, was likely assisted by its high reproductive rate, ideal temperatures and human movement, especially along commerce and trade routes. As a species with origins from temperate regions where fruit is seasonally available (re: Japan/SE Asia), it is likely that SWD has some capacity to vertically migrate either daily or seasonally from lower to higher altitudes (*vice versa*) to avoid extreme temperatures (Mitsui et al. 2010; Tait et al. 2018). The potential ability for SWD to self-regulate the temperature of its environment through movement or dispersal (vertically or otherwise) adds even more complexity into the continued efforts to map optimal reproductive temperature zones and risk models. Still, there is much to learn about the movement capabilities of SWD, including the prospect of long-distance migration.

The ability of SWD to exploit microhabitats through vertical or horizontal movement often negates the predictions made from risk models which take in to account gross landscape features. For example, in central California, was the presence of SWD in orange orchards at the peak of summer where temperatures regularly reached 43 °C (Bellamy Pers. Obs.). Lab studies and population models would suggest that SWD would not be able to survive at these temperatures. Yet SWD were observed completing their life cycle in fallen oranges, shaded by the trees, which had been opened up by rats, birds, or mice once on the ground. The drip systems provided humidity, perhaps more critical than temperature for SWD (Tochen et al. 2016), and kept the ground temperatures in the shade well below 27 °C. Thus, SWD populations were able to remain viable despite the extreme temperatures which should have supported a different conclusion based on laboratory results (*vida supra*).

Pathway implications for New Zealand and Australia

Much of the international literature mentions human-mediated transport of fresh produce as the key means of spreading *D. suzukii* into new countries and regions within countries. For a *D. suzukii* incursion to occur via infested fresh fruit a number of steps must take place:

1. Infestation
2. Survival of post-harvest treatment
3. Survival during transport
4. Entry
5. Development through to adulthood (for egg/larval/pupal life stages)
6. Exposure to a suitable feeding host
7. Locating a mate (unless a mated adult female enters)
8. Locating a suitable host for oviposition

These steps are discussed in detail in the pathway risk analysis that the Ministry for Primary Industries has undertaken for *D. suzukii* for fresh produce from the USA and the pest risk analysis that the Australian Department of Agriculture, Fisheries and Forestry has conducted for *D. suzukii* (DAFF 2013; MPI 2012). These documents are a good basis for assessing the risk associated with the pest and the fresh produce pathway[1] and this document does not seek to replicate the analysis contained within these documents.

[1] *D. suzukii* emergence has also been reported from flowers of two plant species: *Styrax japonicus* and *Camellia japonica* (Mitsui et al 2010; DAFF 2013) though the probability of importation via trade in fresh flowers was assessed as extremely low in the DAFF risk assessment (DAFF 2013).

Fresh fruit pathways into New Zealand and Australia are heavily regulated to manage biosecurity risk from pests such as *D. suzukii*. Potential fresh fruit pathways include:

- Shipments of commercial produce
- Airfreighted commercial produce
- Air passengers
- Passengers arriving by sea
- Mail

New Zealand has two interceptions records for *D. suzukii* - five dead larvae were detected in nectarines shipped from the USA as sea cargo in 2012 (MPI personal comm, 2019) and larvae were detected in a single orange in a consignment from the USA in April 2019 (MPI 2019). In addition, interceptions of live Drosophilid larvae (not identified to species level) have been made, indicating that early Drosophilid life stages can survive transit on fresh produce. Adult Drosophilids (not *D. suzukii*) have also been intercepted at the New Zealand border (MPI 2012). The life stages considered most likely to enter are eggs and early instar larvae (MPI 2012). Eggs, larvae or pupae may be present inside fruit and difficult to detect, particularly in low number or during the early stages of attack (MPI 2012; ODA 2010). Egg laying often occurs near harvest and early symptoms are subtle, meaning infestations in fruit can go undetected (ODA 2010). In contrast to the immature stages, adult flies are mobile and able to move off fruit during harvesting and processing (MPI 2012).

Commercial fresh fruit pathways have a number of measures in place that are considered to be effective against *D. suzukii* and many other pests. Measure options to manage the risk from *D. suzukii* in imported fresh fruit include area freedom, a systems approach to ensure imported fruit is not infested with *D. suzukii* or application of a suitable treatment (DAFF 2013). Fresh produce treatments that are available and efficacious against *D. suzukii* include fumigation with methyl bromide or fumigation with sulphur dioxide/carbon dioxide followed by cold disinfestation (DAFF 2013).

3.2 Detection sites

Previous incursions around the globe can provide useful information about possible first detection sites in new regions, such as Australia or New Zealand. The different aspects of detection sites are explored below.

Temperature, humidity and altitude

The interaction between temperature, moisture and altitude is important for *D. suzukii* survival, overwintering ability and population growth. *Drosophila suzukii* appears to be somewhat temperature sensitive with a decrease in captures in the hottest part of the summer in locations such as Florida (DAFF 2013; Dean 2010). *Drosophila suzukii* overwinters as an adult and it is thought to seek shelter from adverse conditions (Asplen et al. 2015). It has been hypothesised that populations move up and down in altitude seasonally to regulate temperature and/or to take advantage of host availability (Mitsui et al. 2010; Asplen et al. 2015). *D. suzukii* has been found in

Europe from 4m above sea level (Mortelmans et al. 2012) to 1550 m above sea level (Calabria et al. 2012), indicating a very wide altitude range. Drosophilids tend to be sensitive to desiccation (Walsh et al. 2011) and *D. suzukii* appears to prefer humid microclimates (SWD workshop Melbourne 29 October 2018).

Spotted wing drosophila, as other dipterans, undergo three larval stages and a pupal stage before becoming an adult. Also, commonly, *D. suzukii's* development rate has been found to be temperature dependent with developmental time decreasing with increasing temperature. This trend holds true until hotter temperatures eventually induce thermal stress. Laboratory studies of temperature-dependent development vary, with *D. suzukii* developing most rapidly between 26 °C and 28 °C at constant temperatures and exhibiting highest adult emergence rates between 20 °C and 26 °C when held at constant temperatures (Asplen et al. 2015; Kinjo et al. 2014; Tochen et al. 2014)
(Table 4).

Table 4 shows table 1 (from Hamby et al. 2016) includes a summary of published experiments conducted at temperatures between 20 – 27°C showing mean development times from egg to adult

Host substrate	Temp. (°C)	L:D	Humidity (%RH)	Density #*D. suzukii*	Development (days)[a]	Reference
Blackberry agar	24–27	16:8	80	ND	10.2	Bellamy et al. (2013)
Blueberry	25	13:11	ND	10	10.6	Jaramillo et al. (2015)
Blueberry	20.6	16:8	71	≤5	16.3	Tochen et al. (2015)
Blueberry	22	16:8	60–70	≤5	14.0[b]	Tochen et al. (2014)
Blueberry	26	16:8	60–70	≤5	10.9[b]	Tochen et al. (2014)
Blueberry agar	24–27	16:8	80	ND	10.7	Bellamy et al. (2013)
Cherry	22	16:8	60–70	≤5	14.0[b]	Tochen et al. (2014)
Cherry	26	16:8	60–70	≤5	10.8[b]	Tochen et al. (2014)
Cherry agar	24–27	16:8	80	ND	9.7	Bellamy et al. (2013)
Grape agar	24–27	16:8	80	ND	12.1	Bellamy et al. (2013)
Grape	25	16:8	60	ND	16.9	Lin et al. (2014a)
Media	22	15:9	25	1	12.8	Emiljanowicz et al. (2014)
Media	20	12:12	50–65	5	14.9	Hardin et al. (2015)
Media	20	12:12	60	50	16.8[b,d]	Asplen et al. (2015)
Media	20	12:12	60	50	17.1[b,e]	Asplen et al. (2015)
Media	25	13:11	ND	10	11.7	Jaramillo et al. (2015)
Media	25	16:8	60	1	11.3[c]	Kinjo et al. (2014)
Media – molasses	20	12:12	50–65	5	15.6	Hardin et al. (2015)
Media – yeast	20	12:12	50–65	5	15.5	Hardin et al. (2015)
Peach agar	24–27	16:8	80	ND	10.3	Bellamy et al. (2013)
Raspberry	20	12:12	50–65	5	14.7	Hardin et al. (2015)
Raspberry agar	24–27	16:8	80	ND	10.1	Bellamy et al. (2013)
Strawberry agar	24–27	16:8	80	ND	10.9	Bellamy et al. (2013)

[a] Published mean development time in days for either both sexes mixed or females only, SE are not reported numerically in all publications and therefore are not reported

[b] Females only

[c] Development of 1st instar larvae to adult determined by summation of mean development time from 1st instar larva to pupa and pupa to adult

[d] French population

[e] Spanish population

The broadly reported maximum temperature ranges provided (*vida supra*), likely due to differences in experimental methodology, are mirrored in investigations examining minimum developmental thresholds. The minimum threshold average daily temperature for development has been estimated to be 11.6 °C under fluctuating natural conditions (Tonina et al. 2016) and 7.2 °C at constant laboratory conditions (Tochen et al. 2014). Of relevant concern, these temperature ranges are common throughout the central south and southeast regions of Australia, including Tasmania, and the coastal agricultural regions of New Zealand.

Further, there has been a recent identification of a cold-tolerant winter morph in North America. Examining the lower developmental thresholds reported in the two papers above would suggest the population range of *D. suzukii* should occur only in warm temperate areas where the winter temperatures remain above 7.2 °C. In reality, this is not the case and, in fact, large populations of *D. suzukii* can be found thriving in regions experiencing extremely cold winter temperatures (e.g. British Columbia, Canada: lows less than -10 °C in the months of Jan and/or Feb). Shearer and colleagues (2016) identified an overwintering morph differing from the summer morph in both physical and reproductive characteristics. The transition in the population's morph ratios appears to occur when the temperatures pass between 10 – 20 °C with the winter morph dominating populations when below 10 °C and the summer morph being most prevalent at temperatures above 20 °C. Female *D. suzukii* winter morphs were shown to survive at 1 °C for up to 150 days (LT_{50} = 115 d) (Shearer et al. 2016), whereas the summer morphs survived just 42 days (LT_{50} = 28 d). The importance of this discovery is that it expands the *D. suzukii* risk modelling ranges to include regions where winter temperatures can be below 0 °C.

Seasonality

In Germany and other European countries trap captures tend to begin to increase in spring (Briem et al 2018). In some places, such as parts of the United Kingdom and Florida, *D. suzukii* is detected in traps year-round (Asplen et al 2015; Dean 2010; SWD workshop Melbourne 29 October 2018). In the southern hemisphere, *D. suzukii* has been has been detected in March, December and February in Argentina (Lavagnino et al. 2018) and February and August in Brazil (Zanuncio-Junior et al. 2018) and January in Uruguay (Gonzales et al. 2015).

Land use and hosts

The most common land use for first detections (as listed in Table 2) is horticultural production areas – places where crops were being grown for harvest, with thin-skinned berries (e.g., caneberries, blueberries, strawberries) and stone fruits (e.g., cherries, peaches, apricots, plums) being particularly susceptible to infestation (Bellamy et al. 2013). In the US, raspberries and strawberries appear to be preferred hosts for *D. suzukii* (Bellamy et al. 2013; Burrack et al. 2013), with other crops like blueberries, also experiencing economic damage (Rodriguez-Saona et al 2019). Certain fruits (e.g., apples, oranges, pears, tomatoes) can also be infested if split or previously damaged by birds, animals, rot pathogens, or farm equipment (Bal et al. 2017; Lee et al. 2011), but SWD is typically not a significant pest of these crops. However, a recent survey conducted in Michigan (US) of commercial crop hygiene practices, wine-making facilities and cideries, revealed all of the dropped apples, pears, grapes, and raspberries in the crops studied and 40% of apple and 100% of grape fruit pomace evaluated were found to contain SWD with the highest numbers collected from dropped grapes and pears (Bal et al. 2017), despite the reportedly low risk of SWD for several of these crops.

However, first detections also occurred in wilderness areas, private gardens, and urban areas and in one instance, in a greenhouse. It is possible that the higher number of first detections in crops may be due to trap placement as opposed to a preference for this type of land use. A number of invaded areas have reported higher trap counts in wilderness areas and woodland as opposed to crops (Asplen et al. 2015). These many wild plants can serve as potentially important hosts (Mitsui et al. 2010; Cini et al. 2014; Poyet et al. 2014; Lee et al. 2015b), thus increasing the risk of establishment and difficulty for management by providing commercial off-season hosts in which to continue their life cycle. In Europe, common forest hosts include wild *Vaccinium* spp, *Fragaria* spp, *Rubus* spp (Alspen et al. 2015) and the strawberry tree (*Arbutus unedo*) (Asplen et al. 2015). The invasive species American black cherry (*Prunus serotina*) may also be an important host - infestation rates of up to 70% have been seen at one woodland site (Poyet et al. 2014). Studies have shown that adult flies take refuge in wild habitat around raspberry fields and then migrate back into the raspberry crop when fruit are present (Briem et al. 2018; Klick et al. 2016).

Many researchers have examined host potential and suitability under laboratory conditions where the larval substrate is varied in development experiments, with the understanding that larval host nutritional quality impacts *D. suzukii* development time and survivorship (Aly 2018; Bellamy et al. 2013; Burrack et al. 2013; Hardin et al. 2015; Jaramillo et al. 2015; Lee et al. 2011). Under controlled settings, SWD development on various fruit hosts varies significantly by fruit host (Table 4). Interestingly, *D. suzukii* tends to perform better in no-choice assays on commercial hosts when compared to the non-crop and ornamental hosts under similar conditions (Lee et al. 2011, 2015b). Among the commercial hosts that have been evaluated in the laboratory, such as cherries, blackberries, raspberries, and strawberries, *D. suzukii* seems to better develop on raspberries (Lee et al. 2011; Bellamy et al. 2013; Burrack et al. 2013; Tochen et al. 2014), paralleling observations in commercial settings.

While SWD's ovipositor allows for oviposition in fresh fruit hosts, not all hosts are equivalent. The differing physical properties of the fruit hosts' surfaces likely limit oviposition and, consequently, oviposition preferences to varying degrees. Spotted wing drosophila oviposition preference varies significantly between fruit hosts (Bellamy et al 2013), and has been correlated with ripeness, pH, total soluble solids or Brix, skin penetration force, firmness of flesh, and indumenta (fuzz) (Burrack et al. 2013; Hampton et al. 2014; Ioriatti et al. 2015; Lee et al. 2011; Lee et al. 2015b; Little et al. 2017).
Understanding the physical characteristics that limit SWD oviposition may lead to management practices which reduce egg deposition events. For example, fruit susceptibility can be mitigated using compounds such as foliar-sprayed calcium silicate on blueberry fruit, which increases the penetration force needed to pierce the epidermis (Lee et al. 2015a; Rodriguez-Saona et al. 2019). More eggs are laid on fruit without indumenta or where previous damage to fruit allows flies to bypass the indumenta, and on fruit with lower skin penetration force, higher pH, and higher total soluble solids (Bellamy et al. 2013; Burrack et al. 2013; Lee et al. 2015a; Stewart et al. 2014). In laboratory no-choice assays, more eggs were laid in raspberries compared to blackberries, blueberries, and strawberries (Bellamy et al. 2013; Burrack et al. 2013). Raspberries tend to be among the most preferred fruit hosts in laboratory choice tests (Bellamy et al. 2013; Lee et al. 2011), and are infested at a greater rate than blackberries in the field (Burrack et al. 2013). Indeed, raspberries are among the fruit hosts with the lowest skin penetration force, 8.53 ± 0.31 cN as measured by Burrack and colleagues (2013), and between 5.5 and 20.2 cN for ripe fruit as measured by Sexton et al. (1997). Further research is needed to investigate the differences in soft fruit and berry skin thickness and its relation to SWD oviposition success. Results provided from this work could inform soft-skinned fruit/berry breeding programmes.

A novel methodology for indexing the relative potential of hosts to function as resources (Host Potential Index – HPI) was developed as a practical framework to express relative host potential based on combining results from one or more independent studies, such as those examining host selection, utilization, and physiological development of the organism resourcing the host (Bellamy et al. 2013). The results from the interactions of *D. suzukii* with seven ‘‘reported’’ hosts (blackberries, blueberries, sweet cherries, table grapes, peaches, raspberries, and strawberries) in a postharvest scenario were analysed using the HPI. Four aspects of SWD-host interaction were examined: attraction to host volatiles; population-level oviposition performance; individual-level oviposition performance; and key developmental factors. Application of HPI methodology indicated that raspberries (HPI = 301.9 ± 8.39; rank 1 of 7) had the greatest potential to serve as a postharvest host for *D. suzukii* relative to the other fruit hosts, with grapes (HPI = 232.4 ± 3.21; rank 7 of 7) having the least potential (Bellamy et al. 2013). The index is useful in that it can provide a visual representation of the potential to serve as a host when the weight of contribution for each experiment is varied (Figure 2).

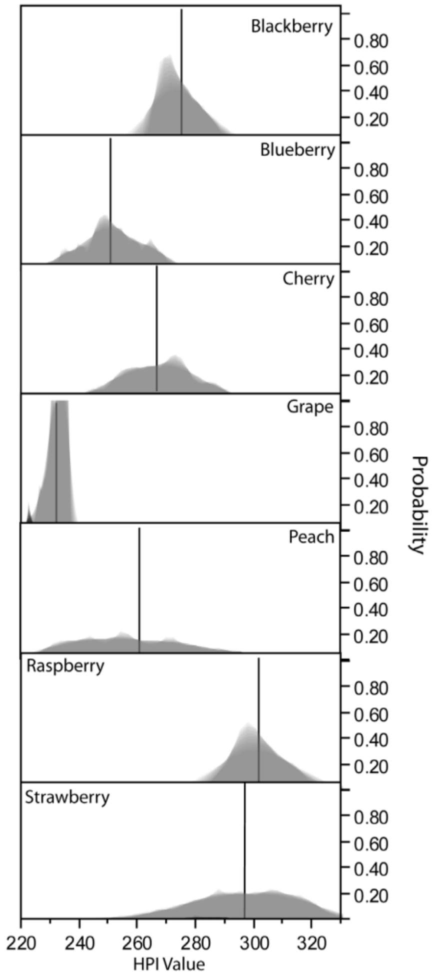

Figure 2. Potential Host Potential Index (HPI) values when weighting coefficients are varied across four studies. The probability distributions of resultant HPI values derived from varying the weighting coefficients for the individual fruits shows the influence of coefficient weight selection. Vertical lines indicate the mean HPI value of each fruit. High x-axis values indicate high host potential.

For further non-host lists, consult Elsensohn and Loeb (2018); Kenis et al. (2016).

Means of detection

There have been two key detection methods in the incursion examples from around the world – trapping and reporting of crop damage following crop inspection. A range of traps (malaise, bottle and tephri traps) baited with a variety of attractants (beer, wine, fruit, apple cider vinegar or a combination) have resulted in first detections, however, since those first detection, improved attractants have been developed. Also of note is that a number of countries (Bulgaria, Poland, Ukraine, Germany and Spain) had trapping programmes in place for a year or more prior to *D. suzukii* being detected – this indicates that these countries may have detected the pest relatively early in its invasion cycle. First trap captures in Europe were generally between July and October.

Detection site implications for New Zealand and Australia

The type of sites where *D. suzukii* is likely to first arrive are difficult to determine from previous incursions, as the first site of detection is not necessarily the invasion epicentre. It is important to note that the invasion site and the 'spreading centre' of an invasive species are not always one and the same (Cini et al. 2014). The first invasion site is not always suitable for spread, meaning the invasion may stem from a secondary invasion site rather than the initial arrival point (Cini et al. 2014).

There are so many inconsistencies with the first detections of *D. suzukii* around the world that any attempt to predict the most likely incursion sites in Australia or New Zealand is speculative. Nevertheless, the below bullet point provides a set factors that could be considered when determining likely detection sites.

- Globally *D. suzukii* has spread to a range of different diverse climatic regions, which means much of Australia and New Zealand could be suitable for establishment.

- It seems that first detections often (but not always) occur in coastal regions. Both New Zealand and Australia have long coastlines with an abundance of suitable host material.

- In terms of land use, crops, wilderness areas and urban environments are all possible detection sites. However, *D. suzukii's* close association with commercially produced crops, this suggests the likely importation pathway into Australia and New Zealand will be with imported fruit that is then on sold to consumers. This indicates that urban areas are likely to be the environment where *D. suzukii* populations first occur.

- Hosts that are developing and ripening are very important – *D. suzukii* must find a food source and then an oviposition host to successfully establish in a new region. *Drosophila suzukii* are known to attack the undamaged fruit of 46 taxa and the damaged or overripe fruit of an additional 54 taxa (DAFF 2013). This means that there are 100 potential hosts for *D. suzukii* to come into contact with upon arrival, each with a different fruiting time (sometime artificially induced, e.g. winter greenhouse crops), in order to complete their lifecycle.

- Landscape level factors such as seasonal movement between hosts or at differing altitudes should be taken into consideration.

- The location of high throughput ports or airports may be important to note, particularly those ports where fresh fruit is being imported from countries where *D. suzukii* is present.

- People are unlikely to consume an infested fruit in its entirety – the damaged portion is very likely to be thrown away. Where the fruit is disposed of is important, with household compost or fruit discarded on the ground or roadsides presenting an elevated risk, as this disposal method is unlikely to kill flies if present (MPI, 2012).

- The location of fruit distributors, wholesalers and retailers may be important to note - disposal of unsold imported fruit via wholesaler or retailer cull piles may present a risk.

- The first trap captures in Europe generally occurred in July-October and built over the season. The Southern hemisphere equivalent to this first trap capture period is January to March. *Drosophila suzukii* has been detected via trapping from August to March in the Southern hemisphere. However, detection year-round may be possible in New Zealand and parts of Australia that have a similar climate to that of the UK, where *D. suzukii* is trapped throughout the year.

In conclusion, when considering potential sites of first detection in Australia and New Zealand the following should be taken into account: climatic suitability, land use, host availability, season, points of entry, origin of fruit imports and fruit disposal.

3.3 Other learnings

Active monitoring

Of the first detections presented in Table 2, 18 were the result of proactive trapping. This indicates the importance of active monitoring for detection (Tobin et al. 2014). Research on trap capture rates suggest that any level of trap capture may be indicative of a high population of *D. suzukii* in the surrounding area (Kirkpatrick et al. 2018b; Kirkpatrick et al. 2017). Therefore, the chances of trapping the first individuals are considered slim without a high density of traps.
Despite the limitations, at present trapping and notification by the public are the only realistic early detection methods available. However, fruit sampling where host fruit is collected and squashed with sugar or salt which causes any larvae to emerge (if present) is another possible option (SWD workshop Melbourne 29 October 2018).

Sampling

Lures

Surveillance for adult female and male *D. suzukii* can be achieved with odourous lures and for larvae with fruit checks. Historically apple cider vinegar has been used to attract adult *D. suzukii* into traps (Beers et al. 2011). Subsequently, lures have been developed based on odours taken from the head space of apple cider vinegar and wine. These include acetic acid, ethanol, acetoin and methionol

(Cha et al. 2012; Cha et al. 2014; Cha et al. 2013; Cha et al. 2015). These odours form the base of two commercially available synthetic lures; Scentry Biological's spotted wing drosophila lure (L962) and the Trécé-Pherocon® spotted wing drosophila lures. The Pherocon lure is available as either a high specificity-low capture lure, or a broad spectrum lure that captures more SWD as well as non-target species. Trécé advertise their traps and lures through their Pherocon brand.
Alpha Scents www.alphascents.com also have a lure, but the details of this lure are not available. See Table 5 for lure supplier and likely cost information.

In addition to the odours identified by (Cha et al. 2014; Cha et al. 2013; Cha et al. 2015), a new synthetic odour combination has been identified and tested. The mixture comprises acetoin, ethyl octanoate, ethyl acetate, penenthyl alcohol and acetic acid. In trials assessing against the current commercial lure provided by Scentry, the odours were placed in yellow jacket traps (Feng et al. 2018). These traps are plastic bags with wasp images printed on them and yellow vanes at the top to allow the odour to be released and the wasps to enter and be trapped. The authors found that the lures had a greater percentage catch of *Drosophila suzukii* to other species captured than the Scentry traps. However, the sensitivity of the lures was low and caught significantly fewer *D. suzukii* than the Scentry trap. The products were reported to be commercially available through ChemTica. However, neither ChemTica nor their international distributors currently sell the product.

Commercially available non-synthetic lures include:

- Droso'attract- a mixture of 75% apple cider vinegar and 25% red wine (Grassi et al. 2015). It is manufactured and sold by Biobest. Biobest also have a red Lynfield-bucket type trap, DrosoTrap, which is recommended to be combined lure. Additional sugar is added to the product once in the trap to support fermentation processes (see Appendix 1).

- SuzukiiTrap is sold by Bioibérica and combined with their trap (a red plastic bottle). SuzukiiTrap is a liquid mixture comprised organic acids and protein hydrolysed (7% of protein) (de los Santo *[sic]* Ramos et al. 2014).

There are a number of other lure providers, however, there is either little information on their products or they do not ship to Australia or New Zealand.

The aforementioned non-synthetic lure and trap combinations are marketed as wet traps. The non-synthetic attractants use the lure as the drowning agent. The synthetic lures are recommended to be used with water and unscented soap to break water tension as a drowning solution, however, dry trapping has also been achieved for the Scentry and AlphaScents lures.

Larval sampling can be done by harvesting fruit the lightly crushing to expose the pulp. This is then immersed in either a salt solution 22.5ml salt to 473 ml water and leaving for 10 mins (Hamby et al. 2014) or a sugar solution 1kg sugar and 5.5L water e.g. https://www.youtube.com/watch?v=jsdcDsJOgoM. Larval infestation rates and numbers of adults trapped with apple cider vinegar or with yeast-baited traps are not well correlated (Hamby et al. 2014), no further comparisons were found.

Traps

The red colour appears to be important in signalling to the flies. In a series of trials to identify the best colour to attract *Drosophila suzukii* with Scentry lures. Red spheres were identified as the best followed by black. Yellow, blue, purple were statistically similar to the red and black, but green and white were the poorest colours (Kirkpatrick et al. 2017). In another trial with Scentry lures a red sphere and a Ladd type trap (red sphere in the centre of a yellow panel) caught x2-2.5 more *D. suzukii* than green, white or yellow panels or clear transparent deli cups in cherry crops (Kirkpatrick et al. 2018a). In raspberry crops in high tunnels, the Ladd trap caught ~x1.8 of the green, white and red panels. Red sphere and panel trap caught more flies than yeast or Scentry lures in a clear cups in cherries. The red sphere, red panel trap and yeast in a cup caught more flies than Scentry in a clear cup. Catch by sex was the same throughout (Lasa et al. 2017)

Table 5. Suppliers of *Drosophila suzukii* surveillance and management products who either ship to or have distributors in Australasia. The current availability and estimated costs (April 2019) either from the websites or from conversations with the distributors. Product labels where available are presented in Appendix 1. Approvals for their use in Australia and New Zealand are not known.

Source	**Cost**	**Published efficacy information**
Bioibérica (Spain) https://www.bioiberica.com/en/products/plant-health/biological-attractants sold as SuzukiiTrap Contact: Ignasi Pons Badrinas ipons@bioiberica.com	~€3.00/L 250-600ml/trap/Season Plus shipping Lure replacement 4-6 weeks	(Kirkpatrick et al. 2017) (Tonina et al. 2018) (Lasa et al. 2017)
Scentry (USA) AU and NZ distributors Contact: grochem@grochem.co.nz info@grochem.com.au	NZD $11.50/lure $14.50/trap Lure replacement 4-6 weeks Note, this is retail price and Growchem indicated that better pricing is likely available for larger quantities	(Kirkpatrick et al. 2017) (Cha et al. 2018) (Wong et al. 2018) (Jaffe et al. 2018) (Renkema et al. 2018) (Kirkpatrick et al. 2018b)
Apple cider vinegar	Variable, available from supermarkets Lure replacement weekly	(Tonina et al. 2018) (Lasa et al. 2017)

Biobest (Belgium) AU and NZ distributors Contacts: kim.amstad@horticentre.co.nz info@bugsforbugs.com.au	Dros'Attract 5L $36.80 (NZD) (for 1 – 144) discount of 10% for quantities 144 and over DrosoTrap $7.35 ea. (NZD) (for 1 – 1800) discount of 5% for quantities 1800 and over Prices are based on euro .60 = NZD 1.00. Lure replacement 200ml/trap/2 weeks	(Kirkpatrick et al. 2017) (Tonina et al. 2018) (Renkema et al. 2018)
Trécé-Pherocon http://trece.com/contact/ AU distributor	No response provided by supplier	(Kirkpatrick et al. 2017) (Cha et al. 2018) (Tonina et al. 2018)
AlphaScents Contact: sales@alphascents.com	$5.00/lure USD $2.31/trap USD Lure replacement every 30 days Trap is a sticky yellow sheet hung vertically. Better pricing available for large orders	(Kirkpatrick et al. 2017)
ISCA Hook SWD- experimental lure and kill product for pest management AU distributor Organic Crop Protectants info@ocp.com.au	Unknown- no response from OCP	(Klick et al. 2019)

Product comparisons

The lure provided by Scentry has been the focus of many publications related to surveillance and has been compared with the aforementioned lures.

The Scentry lure catches both males and females virgin and mated females in a combination with yeast and sugar plus water and unscented soap as a drowning solution. The odours from fermenting baits is good at attracting young *D. suzukii* and the host odours good for mature *D. suzukii* (Wong et al. 2018). The addition of yeast and sugar to the Scentry lure improved catch over Scentry alone (Jaffe et al. 2018), but as with all of the other lures, there is a lot of by-catch when surveying for *D. suzukii*. Catch is often greatest when fruit are ripening rather (mature) rather than when fruit is developing (younger). However, this may be confounded by seasonal differences between developing fruit and ripening fruit as over the course of time this has allowed for the SWD population to build up.

Comparisons that focussed on the role of odour rather than trap colour determined that those baited with either yeast (12.5g active dry yeast, 50G sugar and 355ml distilled water), Alpha Scents lure or the Scentry lure outperformed those baited with Pherocon or Bioibérica lures (Kirkpatrick et al. 2017). Further trials comparing Scentry to Pherocon in different crop types showed that in a blueberry crop, the Scentry lure detected *D. suzukii* up to 10-days before the Pherocon lure and 3-weeks prior to detection of larvae in fruit. However, in a raspberry crop, Scentry detected *D. suzukii* only 4-days prior to Pherocon and on the same day as larvae were detected in fruit (Cha et al. 2018).

A trial compared Biobest, Biologische Essigfliegenfalle, Pherocon and Bioibérica and apple cider vinegar. All lures outperformed apple cider vinegar. However, Pherocon alone (without apple cider vinegar as a drowning solution) had significantly lower catch than the other commercial lures. All lures had low selectivity (Tonina et al. 2018). Biobest, Biologische Essigfliegenfalle and apple cider vinegar needed to be replaced approximately weekly, whereas Pherocon and Bioibérica needed to be changed approximately 4-6 weekly. Further, Pherocon and Bioibérica worked better in cooler temperatures in the early spring, detecting flies before Biobest. The authors recommended Bioibérica. A further test with Bioibérica showed that when tested against a mix of apple cider vinegar and 10% ethanol plus 0.417 g yeast and 1.1 g sugar and 20 ml water. The apple cider vinegar, ethanol, yeast, sugar and water combination caught 4-7 times as many *D. suzukii* as the Bioibérica lure in a guava orchard (Lasa et al. 2017).

A trial investigated the presence of *D. suzukii* in winter strawberry crops from 24 December until 17 March 2015-2016 in central (warmer) and northern (cooler) Florida ,USA (Renkema et al. 2018). The average minimum temperature in central site was 11.5°C, 8.6°C and 12.3°C for early, mid and late winter; northern site 8.8°C, 6.2°C and 9.9°C for early, mid and late winter. Biobest statistically out performed Scentry in catching female flies but not male flies in a warmer site and males in a cooler site (no data on females). However, overall catch was very low with the greatest difference in trap catch being recorded between the males at the cooler site (Biobest, 0.36/trap/day; Scentry 0.13/trap/day). Female winter morphs were that were trapped at the central (warmer) site were checked for the presence of eggs. Approximately 65% of the female had eggs present of which approximately 20% were carrying mature eggs at early, mid and late winter assessments. There was increased catch near the edge of strawberry plots where they bordered woodlands.

Probability of detection

An estimate has been derived for the population density in a cherry crop based on catch in a trap using the Scentry lure on a red sticky panel trap (Kirkpatrick et al. 2018b). From the combined data from two years, two mark-release-recaptures studies that on average ran for 37.5 d led the authors to estimate that catch in a single trap ≈ 71 flies per hectare.

Using the values presented in Kirkpatrick et al. (2018b) to determine the effective sampling area of the lure and panel trap combination (Kean 2015; Stringer et al. 2017), we have estimated the probability of detecting variable population densities of *D. suzukii* populations on a single day with a varying density of traps (Figure 3), and the probability of detecting a population of 10 *D. suzukii* per hectare over time with a varying density of traps (Figure 4)

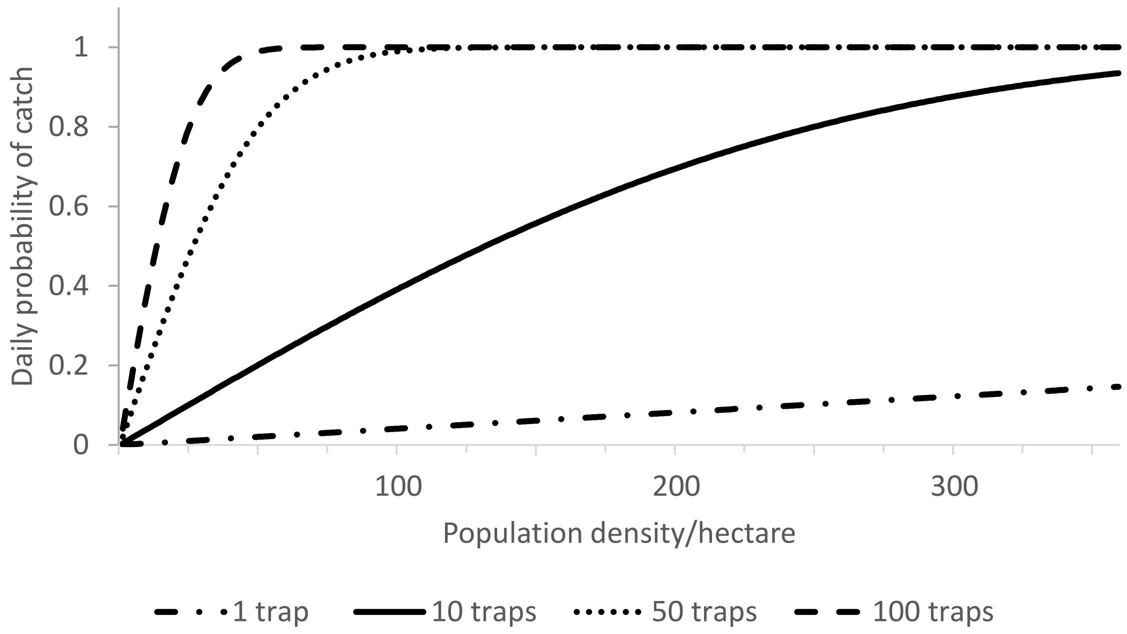

Figure 3. The estimated probability of detecting a population of *Drosophila suzukii* on one day with a varying density of Scentry-baited red panel traps per hectare using data presented by (Kirkpatrick et al. 2018b)

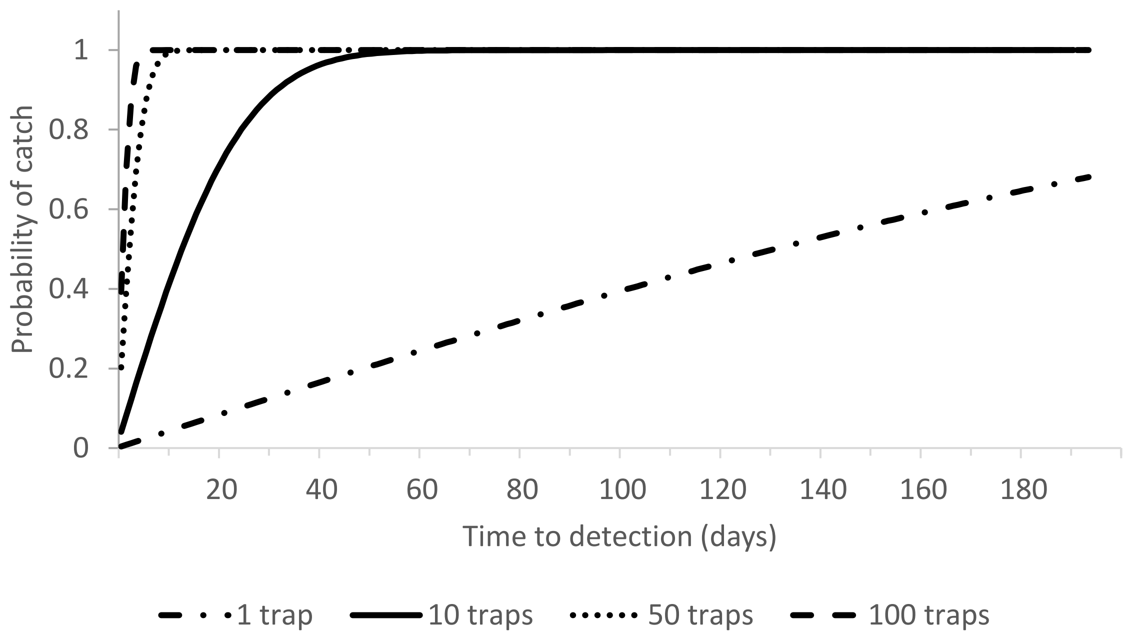

Figure 4. The estimated probability of detecting a population of 10 *Drosophila suzukii* per hectare over time with a varying density of Scentry-baited red panel traps from data presented by (Kirkpatrick et al. 2018b). This assumes the population density remains constant through time.

Diagnostics

In some instances, the response to *D. suzukii* was delayed due to misidentification – the fly looks similar to a number of other species present in some countries. In California *D. suzukii* was initially thought to be *Drosophila biarmipes* (Hauser, 2011). The 'first detection' in Chile was disproven following the realisation that the specimens collected were not in fact *D. suzukii* (EPPO, 2016). This indicates the importance of rapid and reliable diagnostic protocols for all life stages.

Phenotypic identification

The magnitude of economic damage credited to *D. suzukii* can, in part, be attributed to the morphology of the female oviscape valve (bilateral pair of ovipositor plates) which has enabled their utilization of fresh fruit hosts (Atallah et al. 2014; Hauser 2011). It is the alternate motion of the oviscape valve against one another in a back and forth sawing motion which provides a functional basis for piercing fruit tissue for most insects (Austin and Browning 1981). The oviscape valve of *D. suzukii*, however, is larger in area than most other *Drosophila* and has thick, heavily sclerotized bristles near the distal tips of the valve (Figure 5). These tips are the region of the valve that comes into contact with fruit (Atallah et al. 2014). In comparison to *D. subpulchrella*, a closely related species, female *D. suzukii* have more modified bristles on the lateral side of the oviscape valve as well as more streamlined knife-like or blade-like shape as measured by the oviscape valve's length-to-width ratio (Atallah et al. 2014). Contrary to other related fruit fly species which must utilize fruit where the skin's integrity has been compromised through decomposition, this morphological adaptation allows female SWD to penetrate normally resistant fresh fruit skin to deposit her eggs.

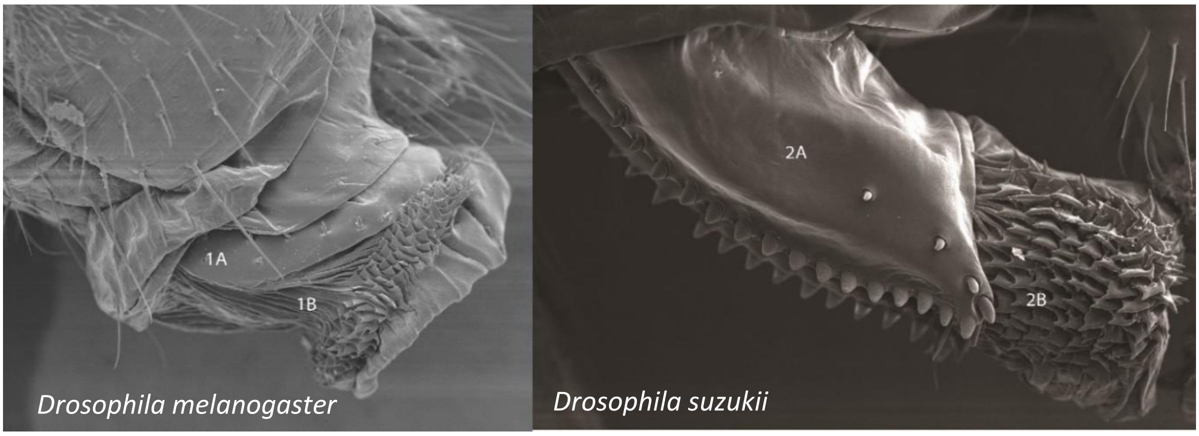

Figure 5. (Left) *Drosophila melanogaster* oviscape valve (1A) lacking sclerotized teeth and eversible membrane (1B) with small band of denticles. (Right) *Drosophila suzukii* oviscape valve (2A) showing extensive sclerotized teeth and eversible membrane (2b) with prominent denticles. Unpublished images from Dave Bellamy (Plant & Food Research) and Dennis Margosan (USDA-ARS).

During the act of egg deposition, the oviscape valve begins reciprocating and creates a small incision in the fruit surface. Between the two ovipositor plates of the oviscape valve lies the eversible membrane which has posteriorly-oriented denticles. This dual-purpose membrane is believed to serve both as, 1) a ''linear ratchet'' producing unidirectional movement of the egg along the ovipositor (Austin and Browning 1981); and, 2) a means to anchor the ovipositor at an optimal depth for egg deposition (Hamby et al. 2016). As the egg moves down the eversible membrane, it fully expands, causing the denticles to become erect, anchoring itself to the fruit skin and flesh as the egg passes through and is released (see Figure 6). Perhaps the most essential of SWD's adaptations regarding its ability to utilize fresh fruit, the heavily toothed eversible membrane is the least studied and least understood morphological structure involved with SWD oviposition.

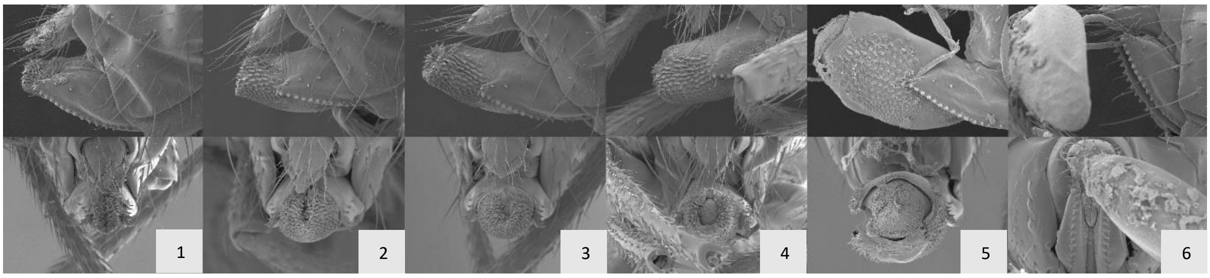

Figure 6. Oviposition sequence viewed from the side (top row) and behind (bottom row) for *D. suzukii*. Slide 1 shows the ovipositor (oviscape valve and eversible membrane) in normal state. Slides 2-5 sequences the egg as it passes through the eversible membrane. The eversible membrane is believed to act as an anchoring mechanism allowing proper egg deposition depth during oviposition in fresh fruit. Slide 6 ends the sequence where the egg is released. Slides from Dave Bellamy and Dennis Margosan (USDA-ARS).

Molecular identification

Molecular markers have been developed to identify predators of *D. suzukii* (Wolf et al. 2018). Primer pair Dro-suz-S390 and Dro-suz-A380 were developed. The primer pair can identify *D. suzukii* in samples and may falsely identify *Drosophila subpulchrella* as *D. suzukii.* This closely related species has not been tested to date. The molecular methods have been tested against a number of other *Drosophila* species to confirm that they will not result in false positive returns (Table 6). This research highlights the possibility to develop a molecular diagnostic tool that may be able to sample the liquid in which *D. suzukii* that have been attracted to traps drown if using wet traps for fly surveillance.

Table 6. *Drosophila* species correctly identified as not being *D. suzukii* by molecular methods.

Drosophila ambigua	*Drosophila littoralis*
Drosophila biarmipes	*Drosophila melanogaster*
Drosophila bifasciata	*Drosophila nigrosparsa*
Drosophila busckii	*Drosophila obscura*
Drosophila deflexa	*Drosophila repleta*
Drosophila fenestrarum	*Drosophila rufifrons*
Drosophila funebris	*Drosophila simulans*
Drosophila helvetica	*Drosophila subobscura*
Drosophila histrio	*Drosophila subsilvestris*
Drosophila hydei	*Drosophila testacea*
Drosophila immigrans	*Drosophila transversa*
Drosophila kuntzei	*Drosophila tristis*
Drosophila limbata	

Controlling spread during the early stages of an incursion

Rapid spread within countries may have been facilitated in some instances by a lack of domestic quarantine or movement control being imposed - when reviewing the EPPO records of first detection a number of entries imply that no official measures or phytosanitary actions were taken. It seems that by the time *D. suzukii* was first detected in many countries it was already relatively widespread, making containment difficult. In Brazil, reduced access to insecticides registered for use against *D. suzukii* was also recognised as an issue (Zanuncio-Junior et al. 2018).

To have any potential to eradicate or slow the spread of *D. suzukii* after detection, it must be found early in its invasion and host plant movement controls must be placed immediately- effectively treating it like a tephritid fruit fly. This species is highly fecund, develops rapidly, and uses a large number of fruits from commercial to weed species as larval hosts. To our knowledge there are no trapping programmes operating in Australia and New Zealand for the early detection of this species, thus the first detection is likely to come from the public or from a grower. New Zealand has a native moth that uses *Rubus* plant stems and fruits for larval development, the raspberry budmoth *Carposina rubophaga.* There is potential for members of the public to confuse any host fruit damage from *D. suzukii* with this species so not report fruit damage.

4. Potential industry impact

Drosophila suzukii is globally recognised as a significant and challenging pest. The adult female has a serrated ovipositor which is used to cut soft-skinned fruits for egg laying (Walsh et al. 2011). The oviposition wound creates an opportunity for other insect pests and for entry of fungal or bacterial pathogens. As *D. suzukii* larvae develop inside the fruit they feed on the flesh, resulting in soft, sunken and discoloured areas (Mazzi et al. 2017; Walsh et al. 2011). This damage renders the fruit unmarketable. The flow on detrimental impacts from *D. suzukii* can take many forms, including yield loss, management costs, post-harvest sorting costs, and potentially market access implications.

Worldwide, the economic impacts of this pest for horticultural industries have been significant. While it is difficult to estimate the potential impact if *D. suzukii* were to arrive in New Zealand or Australia, much can be learnt from the North American, European and South American experiences. In the USA for example, national crop loss from *D. suzukii* has been estimated to exceed $700 million annually (Bolda et al. 2010; Walton et al. 2016). Yield loss estimates from observations in 2009 ranged from negligible to 80% (Bolda et al. 2010; Walsh et al. 2011). In 2013 in southern Brazil, a 30% loss in strawberry production was attributed to *D. suzukii* (Deprá et al. 2014; Zanuncio-Junior et al. 2018). In the province of Trento, Italy, it has been estimated that berry growers incurred a 25%–35% reduction in production value in 2010 (which varied depending on crop) (Mazzi et al. 2017). The range in these figures indicates that significant uncertainty remains around the true economic impact of *D. suzukii*, which is highly dependent on crop type, location and *D. suzukii* population growth in the area.

Drosophila suzukii hosts can be split into two categories: those that are hosts when undamaged (including unripe fruit – a unique trait), and those that appear to host *D. suzukii* only if the fruit is damaged in some way (split, dropped, overripe etc.). *Drosophila suzukii* does not appear to be a significant pest for crops where only damaged fruit is attacked (Alspen et al. 2015) which include apple, pear, tomato, persimmon, banana, fig and loquat, among others (DAFF 2013; Vilela and Mori 2014), Those that are hosts when undamaged are at higher risk and of more concern. These include grapes and many berry fruit and stone fruit, with blackberry, grapes and cherries being identified as preferred hosts (DAFF 2013).

Impacts in Australia

Based on the figures in the Australian Horticulture Statistics Handbook 2017-2018, over $2 billion of fresh fruit production (40 per cent of total fresh fruit production value), and $545 million of fresh export value (50 per cent of fresh fruit export value) would be threatened by an incursion of SWD. The breakdown of these crops is presented below.

Table 7 : Selection of commercial crops grown in Australia that are reported as *Drosophila suzukii* hosts (on undamaged fruit).

Crop	Value (millions)	Value of export (millions)	Major production states
Table grapes	$543.7	$384.1	Vic., NSW
Strawberries	$445.0	$29.7	Qld., Vic.
Summerfruit	$397.8	$65.1	
Apricots			Vic., SA, Tas.
Nectarines / Peaches			Vic., NSW, SA
Plums			Vic., NSW, WA
Blueberries	$309.0	$4.4	NSW, Tas.
Rubus	$157.3	<$0.1	Vic., NSW, Tas., Qld.
Cherries	$148.7	$62.2	Vic., NSW, Tas., SA
Total	$2001.5	$545.5	

Considered at a value per state, Victoria and New South Wales are evidently the states that would be most impacted by uncontrolled populations of SWD in respect to the total value of production. However, this potential impact needs to be considered against the local climatic suitability and relative impacts to different crops. As a result, individual states might be more or less impacted as a proportion of their respective horticultural production.

Table 8 : Value of production "at risk" from *Drosophila suzukii* by Australian state.

State	Value of "at risk" production	Greatest value crops impacted by SWD
Victoria	$946m	Table grapes, peaches/nectarines, strawberries
New South Wales	$442m	Blueberries
Queensland	$267m	Strawberries
Tasmania	$125m	Cherries, blueberries, strawberries
South Australia	$111m	Strawberries, cherries, peaches/nectarines
Western Australia	$100m	Strawberries
Northern Territory	$3m	Table grapes

Impacts in New Zealand

New Zealand produces a number of crop species that are reported as *D. suzukii* hosts overseas for undamaged fruit. These are grown commercially for both the New Zealand domestic and export markets. Table 9 below indicates the value of these crops. If *D. suzukii* were to arrive and establish in New Zealand, it is likely that the pest would impact on the dollar value of these crops through reduced yield and any potential market access implications. For these reasons, a number of New Zealand horticultural industries are very concerned about the threat that *D. suzukii* poses.

Table 9: Selection of commercial crops grown in New Zealand that are reported as *Drosophila suzukii* hosts (on undamaged fruit) in the DAFF (2013).

Commercial host crop*	Domestic fresh product value 2016/17 $M (Plant & Food Research and Horticulture New Zealand 2017)	Export fresh product value 2017 $M (Plant & Food Research and Horticulture New Zealand 2017)
Blueberry (*Vaccinium sp*)	21.0	32.3
Boysenberry (*Rubus loganobaccus*)	4.3	-
Cherry (*Prunus avium*)	16.8	71.2
Peach (*Prunus persica*)	13.6	0.7
Plum (*Prunus domestica*)	8.3	0.3
Nectarine (*Prunus persica var. nucipersica /Prunus persica var. nectarine*)	17.1	0.2
Strawberry (*Fragaria ananassa*)	21.3	7.7
Grapes (table) (*Vitis vinifera*)	-	0.8
Raspberry (*Rubus idaeus*)	3.0	-
Blackberry (*Rubus fruticosus*)	-	-
Apricot (*Prunus armeniaca*)	6.4	5.2
Blackcurrants (*Ribes sp*)	1.0	-
Kiwiberry (hardy kiwi) (*Actinidia arguta*)	0.3	3.9
Total	$113.1	$122.3

*DAFF (2013) Final pest risk analysis report for *Drosophila suzukii*.

It is important to note that potential production losses may impact host crops destined for processing as well as those that that are sold fresh. A good example is wine grapes. Although wine grapes are processed and so there is a negligible market access issue around the final product, establishment of *D. suzukii* in a wine production area could cause significant production/yield losses for the wine industry, as badly affected grapes would not be suitable for winemaking. The export value of wine is currently just over $1.7 billion a year, and on average the value of wine grapes leaving the vineyards for processing each year is around $700 million (not including 2019).

5. Future Management

A number of insecticides are used for *D. suzukii* management including pyrethroids such as, zeta cypermethrin and bifenthrin; organophosphates, malathion and phosmet; carbamates like methomyl, and spinosyns such as, spinetoram (Beers et al. 2011; Shawer et al. 2018; Van Timmeren and Isaacs 2013; Van Timmeren et al. 2018). Due to the frequency of pesticide application and the number of *D. suzukii* generations possible per year, there has been concern that resistance to some insecticides will develop in populations, but currently this does not appear to have occurred (Van Timmeren et al. 2018). The frequent use of insecticides has disrupted Integrated Pest Management programmes. Alternative strategies are under development that can complement or reduce reliance on frequent pesticide applications.

These include physical barriers, such as, netting to prevent infestation by *D. suzukii* (Leach et al. 2016). Netting also helps to prevent infestation by a number of other pest insects (Leach et al. 2016). Further, management by orchard hygiene, removing old fruit, and a rapid harvest schedule can reduce fruit infestation rates (Leach et al. 2018).
Lure and kill products are being developed to target only *D. suzukii* thereby limiting the off-target effects from wide application of broad-spectrum insecticides. One such example is ISCA Technologies' SPLAT Hook SWD (Figure 7). This is an experimental pink-coloured bait spray formulation contains phagostimulants and spinosad 0.5% to lure and kill individuals- regulatory approval pending (Klick et al. 2019).

Figure 7. Application (left) of ISCA Technologies' Hook SWD (right)

New developments using an entomopathogenic fungus *Metarhizium brunneum* shows promise in the laboratory (Yousef et al. 2018). However, these are yet to be field tested or formulated for field application.

The use of the sterile insect technique for *D. suzukii* management is being assessed. A dose response trial has been undertaken (Lanouette et al. 2017). The males are more radio resistant and a dose of 120Gy of 4-day old pupae results in 4% residual fertility of irradiated males.

Currently, from overseas studies, there is low efficacy from local biological control agents to use *D. suzukii* as a host, however, there are candidate agents from Asia under investigation (Wang et al. 2019).

6. Gaps

In reviewing the literature, some gaps in our current knowledge were identified.

- There appears to be limited knowledge on natural spread rates of *D. suzukii*, and the spatial distribution of hosts, including weeds, on the landscape. This knowledge would aid in predicting the potential spread of the pest, assuming human-aided spread could be limited.
- It is not known whether the chemical compounds used for attraction of flies into traps or for management of populations overseas are approved for use in Australia or New Zealand and whether treated products would still be accepted by trading partners. This would need to be investigated with the appropriate organisations/authorities in each country. If the compounds are not approved in a country, application for approval for use would need to be undertaken to allow for rapid response to the pest with reduced disruption to affected industries.
- If wet traps were used by local authorities to survey for the presence of *D. suzukii*, a diagnostic tool needs to be developed that can assess samples quickly as a large number of organisms are attracted to current lures. The development of primers that have been used to identify predators of *D. suzukii* show that there is potential to develop a tool that can sample the liquid for the presence of *D. suzukii.* The developed tool would need to be tested in each area to determine whether any of the local organisms attracted to lures would result in false positive results.
- Currently, three synthetic lure show potential for use in a dry trap- a sticky base. The lures have not been tested in fruit fly traps. There is potential that the lures could be placed in red version of current fruit fly traps used in Australia and New Zealand to result in dry specimens. This could be tested with Scentry, Alpha Scents and Pherocon lures. If a diagnostic of liquid can be developed, dry samples could be placed into a liquid for the diagnostic assessment.
- The synthetic lures could be further improved with the addition of odours from fermenting yeast sources. There is probably going to be increased by-catch.

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Appendix 1

See attached sheets

Plant Health AUSTRALIA

CONTROL OPTIONS FOR SPOTTED WING DROSOPHILA

Improving national biosecurity outcomes through partnerships

This report is part of Improving the biosecurity preparedness of Australian horticulture for the exotic Spotted Wing Drosophila (Drosophila suzukii) (MT17005). This project has been funded by Hort Innovation, using the strawberry, raspberry and blackberry, cherry and summerfruit research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not for profit research and development corporation for Australian horticulture.

Project partners

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SWD MANAGEMENT APPROACHES

Spotted wing drosophila (SWD) is an emerging pest overseas that can severely impact on fruit production. Because of this it is considered to be a high priority pest of a number of plant industries (PHA 2011a, 2011b, 2013a; 2013b, 2016; 2017) and is also listed by the Australian Government as one of the country's top 40 National Priority Plant Pests (NPPP 2016). Overseas this pest is managed by a chemical and non-chemical control means.

Effective management of SWD is a challenge owing to its wide host range and short generation time. Overseas SWD can only be managed using a systems approach using both chemical and non-chemical control Within Australia, the wide climatic zones spanned by berry, cherry, grape, and summerfruit growing regions will require unique management recommendations.

Effective management of SWD overseas relies on various management strategies. Of high importance and value is crop hygiene and cultural control practices such as microhabitat manipulation which has been shown to be and effective management tool for SWD. Many cropping systems have moved away from the use of chemicals that impact on Integrated pest management (IPM) systems. Because of this chemical control for SWD is often lower on the list for use as a management tool. Current SWD management approaches include:

1. Make fields less favourable for SWD
    - Cultivar selection
    - Weed fabric
    - Pruning
    - Netting
2. Monitor SWD flies in spring to detect first activity
3. As fruit begin to ripen, sample for larvae
4. Protect ripening and ripe susceptible fruit
    - Weekly application
    - Good coverage
    - Reapplication after rain
    - Rotate chemical classes
    - Consider adult and larval control
5. Post-harvest methods

The cost of management is less than the cost of doing nothing. Doing nothing can result in up to 100% crop loss. In the UK the cost of managing SWD is estimated to be $36-54 million per annum. No single control method will work to reduce SWD populations. Rather multiple methods used as part of an integrated pest and disease management plan is recommended.

This review will focus on all control options available for SWD.

Biocontrols

Given legitimate concerns over the risks and limitations of using a chemical control method, research efforts have focused on the development of environmentally sound and sustainable methods. There is a wide variety of biocontrol agents including fungi, bacteria, viruses and natural enemies of the pest that could be employed in the control programs for *D. suzukii*.

Natural enemies of insect pests are endemic species that occur abundantly in agricultural fields. Natural enemies including pathogens, predators and parasitoids can be specialists or generalists, and they can induce a high level of mortality in their hosts (Flint and Dreistadt, 1998). Biological control approaches based on arthropod natural enemies are currently studied and developed worldwide. The pathogens and insects discussed below are some of the more promising biocontrols that might be applicable in an Australian setting for use when *D. suzukii* establishes in Australia. More research is required and a government process would have to be followed before the biocontrols are actively used in Australia. This could be done as part of preparedness activities for *D. suzukii*.

Bacteria

Photorhabdus luminescens, a member of the Gammaproteobacteria, is a Gram-negative and mutualistic bacterium that lives in the gut of entomopathogenic nematodes belonging to the Heterorhabditidae family (Shawer et al., 2018). Both *P. luminescens* alone and its symbiotic *Heterorhabditis spp*. nematode are known to be highly pathogenic to insects. Once the nematode infects an insect, *P. luminescens* is rapidly released into the haemocoel, where it secretes enzymes and high-molecular-weight toxin complexes (Tc) that disintegrate and bioconvert the body of the infected insect into nutrients, which can be consumed by both the nematode and bacterium. Shawer and colleagues (2018) investigated the possible use of *P. luminescens* to control *D. suzukii* larvae and pupae. The bacterium caused a high mortality of pre-immaginal stages (mortality ranging between 86.7 % - 100 % in larvae and 43.3 % - 63.3 % in pupae) through both oral and contact toxicity. A single bacterial application may maintain a sufficiently high population on fruit for at least 5 days making it an economic control method.

Entomopathogenic bacteria can be used as stand-alone products for pest management in organic farming, their use in rotation or combination with chemicals is strongly encouraged to achieve full efficacy and eco-sustainability. This work shows that *P. luminescens* is a promising tool for the containment of *D. suzukii* population. However, for its technological application in open field conditions, further studies are needed to assess the efficacy and formulation stability of products based on bacterial suspensions in different crops and environmental conditions.

Drosophila melanogaster

In Canada and the UK *Drosophila suzukii* and *Drosophila melanogaster* coexist with different but overlapping resource use in the field (Dancau et al., 2016, Shaw et al., 2018). When forced to completely or partially share resources in the laboratory *D. melanogaster* outcompetes *D. suzukii.* Limiting *D. suzukii* numbers through interspecies competition may eventually be an exploitable method of biocontrol in the field used in combination with other pest management approaches.

Nematodes and predators

Drosophila suzukii populations remain low in the UK with no widespread reports of damage (Cuthbertson and Audsley, 2016). This paper investigated several fungi and nematode biological agents to assess their ability to reduce population numbers of *D. suzukii.* Both the fungus *Isaria fumosorosea* and the entomopathogenic nematode *Heterorhabditis bacteriophora* offer much potential to be incorporated into control strategies to be employed against *D. suzukii* following the laboratory study that found they significantly reduced *D. suzukii* levels (Cuthbertson and Audsley, 2016).

A subsequent study by Hubner and colleages (2017) was performed on entomopathogenic nematodes examining their ability to infect larvae and pupae of *D. suzukii* within directly sprayed fruit, fruit placed on soil, and soil. *Steinernema feltiae* and *Steinernema carpocapsae* were more efficient at infecting soil-pupating host larvae than *H. bacteriophora*. Applied as a soil drench, *S. feltiae* and *S. carpocapsae* were able to infect *D. suzukii* larvae in the soil as well as hidden inside fruit. Direct application of entomopathogenic nematodes on the fruit was less successful, although emergence of flies was significantly reduced.

Another recent study found, *Orius insidiosus* plus *Heterorhabditis bacteriophora,* resulted in an 81 % reduction in blueberries and a 60 % reduction in strawberries (Renkema and Cuthbertson, 2018). It was not as effective in strawberry, likely due to drier substrate conditions. These results were not consistent with the study of Woltz and colleagues (2014) which found that *H. bacteriophora* had low infection rates while the predator *O. insidiosus* decreased *D. suzukii* survival in simple laboratory arenas but not on potted blueberries or bagged blueberry branches outdoors. The use of *O. insidiosus* and *H. bacteriophora* as natural enemies may therefore have a limited success rate.

Although entomopathogenic nematodes should be easily incorporated into existing invertebrate control programmes individually, they are unlikely to control/eradicate populations. Multiple combinations of *O. insidiosus* with other agents (parasitoids, fungal entomopathogens) should be tested.

Parasitoids

Parasitoid species are insects attacking other arthropods in the egg, larval or pupal development stages. Various Drosophila species are subjected to strong selective pressures by egg, larval and pupal parasitoids which play a key role in their population suppression. Most studies agree that Drosophila parasitoids induce a high rate of mortality on their host populations although the level of parasitism varies with breeding sites, local conditions and seasons (Nikolouli et. al., 2017). Studies on natural parasitoid enemies of *D. suzukii* in its invaded regions have shown that parasitism rates are limited, and thus their use is nonefficient for population suppression. This is attributed to the fact that *D. suzukii* exhibits a high level of resistance to the majority of the larval parasitoids tested, associated to a highly efficient cellular immune system and production of a constitutively high hemocyte level.

Two main native parasitic wasp species are known to attack *D. suzukii* pupae in the USA; *Pachycrepoideus vindemiae* and *Trichopria drosophilae* (Rufus Isaacs, personal communication). They were found in laboratory and field studies to successfully reproduce on *D. suzukii* pupae (Gabarra et al., 2015, Rossi Stacconi et al., 2015). In California, the highest parasitism was found in non-crop plants that are refuges for *D. suzukii* e.g. cactus fruits, blackberry in riparian zones and figs and loquat. Release of these parasitic wasps in commercial cropping situations may help manage *D. suzukii*.

Optimized timing of parasitoid release is essential for biological control of any parasitoid. Using a mathematical model Pfab and colleagues (2018) found that based on the climate of the province of Trento (northern Italy) the optimal time of *Trichopria drosophilae* release is estimated to lie between late spring and early summer. These timings would also be consistent in Australia with *D. suzukii* infestation predicted to peak in summer (dos Santos et al., 2017). Using a mathematical model it is predicted that a single parasitoid release event can be more effective than multiple releases over a prolonged period, but multiple releases are more robust to suboptimal timing choices (Pfab et al., 2018).

Progressively, government regulations require the development of host-specialised biological control agents. Extensive field studies and detailed evaluations are required to identify a novel strategy based on introduction and establishment of natural enemies of *D. suzukii* from its native range for a long-term control and determine their effectiveness and safety with regard to nontarget species. A petition is currently in revision to release SWD parasitoid wasps from China into the USA.

In Europe testing on larval parasitoids from *D. suzukii's* native Asia occurred on three Asian larval parasitoids and *Asobara japonica*, *Leptopilina japonica*, and *Ganaspis cf. brasiliensis*, and one European species, *Leptopilina heterotoma* (Girod et al., 2018). *Ganaspis cf. brasiliensis* had the highest level of specificity but variations occurred between two geographical populations tested. A Japanese population was strictly specific to *D. suzukii*, whereas another population from China parasitized *D. suzukii, D. melanogaster* and sporadically *D. subobscura*. These results show that more studies are needed on *G. cf. brasiliensis's* taxonomic status and the existence of biotypes or cryptic species varying in their specificity before field releases can be conducted in Europe and by extension, Australia.

Cultural Control Measures

Exclusion netting

Exclusion netting has been shown to be effective at reducing and delaying *D. suzukii* infection (Leach et al., 2016, Rogers et al., 2016). Nets need to be installed before the fruits begin to ripen to prevent any *D. suzukii* being trapped inside the nets. Cormier and colleagues (2015) found nets over blueberry fields had no significant effect on sugar content, yield and damage from other pests. Blueberries harvested inside the nets were significantly larger than blueberries from control plots which had no treatments applied. A larger study in raspberries investigated research plantings with insecticide and exclusion treatments (Leach et al., 2016). Each of the two control approaches provided significant reduction of infestation in raspberry fruit, but the combination treatment had the lowest overall abundance of larvae in fruit. The combination treatment also delayed the first detected larval infestation by 10 d compared to the untreated plots. Exclusion netting applied to commercial size high tunnels resulted in a significant reduction in overall *D. suzukii* infestation in raspberries, as well as a 3-wk delay in the average first detectable fruit infestation. Importantly raspberry size and quality were not affected by the exclusion treatments, indicating that this approach can be an important component of growers' response to invasion by *D. suzukii* in temperate climates.

While the fine mesh netting would block air flow, it also provides shading, which may be responsible for the similarity in temperature between the high net tunnels and no tunnels (Leach et al., 2016). However, the presence of the netting has the potential to increase the ambient temperature, especially in the later parts of the growing season or in warmer production regions. Extreme temperatures in netted high tunnels is a concern that should be kept in mind for fruit production in regions with different climates. However, there are fan systems and venting options that can be used to minimize the risk of extreme temperatures in high tunnels. Exclusion netting and screening can have additional pest management benefits by acting as a barrier against other pests including insects and birds. Not all pests can be managed by netting for example raspberry aphids and raspberry beetles were relatively unaffected by netting, perhaps because they were already established in plantings (Leach et al., 2016). The cost and potential for intensive labour for installation and maintenance are concerns for growers (Rogers et al., 2016). It is therefore likely that high netted tunnels are a suitable option for small-acerage and organic production systems but not necessarily for large scale set ups.

Cultivar selection

D. suzukii populations are lower early in the growing season. Planting regionally appropriate, early-ripening varieties can therefore help decrease the chances of heavy infestations (Sial et al., 2018). Fruit varieties with thicker skins may also be beneficial when selecting fruit cultivars.

Harvest frequency

Harvesting is a powerful tool for disrupting the SWD life cycle (Rufus Isaacs, personal communication). Increasing the harvest frequency reduces detectable larvae, particularly in the first and second instars. It is recommended to harvest soft fruit every 2-3 days (Sial et al., 2018).

Humidity control

As viability of *D. suzukii* eggs is lower under dry, warm conditions (Burrack et al. 2014), cool humid microhabitats should be avoided by pruning to open up the canopy and using wider tree spacing to increase airflow to the canopy and reduce shading (Sial et al., 2018). Thinning the canopy will enhance spray coverage of insecticides when they are applied (McGinnis et al., 2018). Heavier pruning may even result in larger berries that ripen earlier in the season (Sial et al., 2018).

D. suzukii larvae often emerge from fruit to pupate in a suitably protected place. Some pupating larvae drop to the ground to pupate below the soil surface. Studies suggest that using black plastic weed barrier as a mulch on the ground provides an effective barrier that prevents larvae from pupating underneath the soil surface, reducing *D. suzukii* survival (Sial et al., 2018). The plastic barrier also helps with weed management and water retention. The use of mulches reducing standing water can further contribute to the reduction of humidity in fruit orchards (Hoashi-Erhardt and Bixby-Brosi 2014).

Sanitation

It is important that waste or unmarketable fruit is disposed of correctly. Many farms have their pickers use two buckets, one for marketable fruit and another for waste fruit that are disposed of to reduce the population (Sial et al., 2018). Bagging is often the best method as flies can emerge from unbagged infested fruit. An effective disposal method is to put infested fruit in clear bags sealed and left in the sun for more than 32 hours (Rufus Isaacs, personal communication). This will ensure the larvae are exposed for long enough to the lethal temperate (30 ^{O}C).

Alternative plant hosts present on the edge of the field should be removed to decrease the onset and severity of *D. suzukii* in your crop (Sial et al., 2018).

Control Measures

Incompatible Insect Technique (IIT)

Wolbachia bacteria are naturally present in many insects and often induce a form of conditional sterility called cytoplasmic incompatibility (CI): the offspring of infected males die, unless the eggs are rescued by the compatible infection, inherited from the mother that protects the embryo (Cattel et. al., 2017, Nikolouli et. al., 2017). A long-recognized strategy called the incompatible insect technique (IIT) makes use of the CI phenotype to control insect populations through the mass release of infected males. One of the main points of IIT is that, contrary to SIT that allows both sexes to be released as long as they are sterile, this is not possible for IIT which requires strict male release (Nikoloui et. al., 2017). Indeed, the accidental release of females infected by Wolbachia may result in the replacement of the targeted population by a population carrying the Wolbachia infection. Providing that IIT produced females are compatible with the wild males, the success of IIT could be compromised, since the Wolbachia-infected females would be compatible with either the wild or the released males.

To implement IIT in *D. suzukii*, back and forth *Wolbachia* transfers between *D. suzukii* and *Drosophila simulans* were used to identify *Wolbachia* strains that sterilize *D. suzukii* females (Cattel et.al., 2017). Two *Wolbachia* strains were identified as potential candidates for developing IIT in *D. suzukii*. Importantly the fitness or the mating competitiveness of the sterilized males was not compromised in this study. While a promising control option for SWD several critical steps still need to be tested and developed outside the laboratory before the incompatible insect technique can be used to control *Drosophila suzukii* in a large scale operational program.

Sterile Insect Technique (SIT)

The sterile insect technique (SIT) is a species-specific and environment-friendly method of pest population suppression or eradication. The method is based on the sterilization of males (although releases of both sterile males and females have been successfully used), mainly using ionizing radiation which causes dominant lethal mutations in the sperm. A sufficient number of sterile males to create an overflow ratio over a period of time are released, and they are expected to compete with wild males and mate with wild females (Dyck et al. 2005). Mating results in infertile eggs and the developing zygotes die during early embryogenesis, thus inducing sterility in the wild females. Therefore, over time, the target population declines or it is potentially eradicated.

Apart from being an environmentally sound biological control approach, SIT can be easily integrated with other biological control strategies (parasitoids, predators and pathogens). It is a species-specific method, and the release can be performed from the air thus overcoming any topography limitations. Successful development and application of an SIT operational program depends on: (a) the target population being at low levels; (b) extensive knowledge on the genetics, biology and ecology of the target pest being available before the application; (c) mass-rearing facilities being available and capable of providing large numbers of high-quality sterile insects; (d) a release technology having been developed, and the sterile individuals being efficiently monitored; (e) the releases being applied on an area-wide basis covering the whole pest population and (f) the released sterile individuals not causing any side effects on humans or the environment. The majority of the SIT programs have been applied for the control of fruit fly species as they represent one of the major insect groups of economic importance (FAO/IAEA 2013, https://nucleus.iaea.org/sites/naipc/dirsit/)

First results show X-ray radiation can inhibit the development of all stages (egg, larva, pupa and adult) of *D. suzukii* and induce adult sterility (Follett et. al., 2014, Kim et. al., 2016). Nevertheless, there are some reasonable concerns about the feasibility of SIT for this pest considering its high fecundity and the recurrent immigration of flies into the crop that are not completely confined. The short generation time of *D. suzukii* indicates that SIT management should be intensive, otherwise there is a risk that the population will recover rapidly. In addition, control of large field populations of *D. suzukii* poses an extra challenge for SIT. Nikolouli and colleagues (2017) recommend greenhouses and other confined locations, e.g. exclusion netting high tunnels, as the ideal environment for the biocontrol of *D. suzukii* by using the SIT. Recent studies on plastic- and mesh-covered tunnels have shown that *D. suzukii* populations are significantly decreased in these confined areas, not only due to their physical exclusion, but also because of the unfavorable microclimate that is created in these locations (Rogers et al. 2016). Although complete exclusion is not achievable solely by this technique, its combination with SIT could increase the biocontrol levels of *D. suzukii*, thus limiting the use of insecticides. An additional challenge is that an adequate sexing system is not available for *D. suzukii*, and this means that both males and females will be included in the mass-reared and released flies. Bisexual SIT has been successfully used in the past; however, male only releases have been shown to be by far more cost effective and efficient (Rendon et al. 2000).

Combination SIT/IIT

A promising alternative approach for the biological control of *D. suzukii* is coupling SIT with IIT. In general, female insects are more sensitive to radiation than male insects in terms of the induction of sterility. The minimum dose of irradiation to induce full female sterility can be achieved at 75 Gy while an adequate level of male sterility (99.67%) was obtained at 200 Gy (Krüger et al., 2018). As a result, any accidentally released Wolbachia-infected females will be sterile and the risk of population replacement is reduced. In such a system, the released cytoplasmically incompatible males could also receive a low dose of radiation to ensure complete sterility of females that were not removed (Nikolouli et al., 2018). In this case, the sterility of released males would be due to both Wolbachia and irradiation, while the female sterility would only be caused by irradiation. This combined strategy could in principle be applied to any targeted species for which an adequate sexing system is not available. Integration of such a protocol combining low irradiation dose with CI has proved to be an efficient strategy in programs targeting the population suppression of *Aedes albopictus* (Nikolouli et al., 2017).

Before the application of a SIT and/or IIT program against *D. suzukii,* it is, nevertheless important to consider potential limiting factors that may render the program ineffective. An artificial larval and adult diet along with the factors affecting mass-rearing, like ensuring biological quality and consistency in captive populations, are considerations that need to be developed. SIT and IIT are therefore not ready for use in Australia as a control method if *D. suzukii* was to enter Australia today. SIT and/or IIT may however be a viable control method in the future pending successful outcomes to the hurdles listed above.

Chemical control options for SWD

This section presents information on pesticides that are used overseas for the control SWD and provides commentary on their suitability for use in Australian agriculture based on a comparison of Australian and overseas use patterns.

This report has identified ## pesticides that future Australian Pesticides and Veterinary Medicines Authority (APVMA) Emergency or Minor Use Permits could be developed for. The application for such permits would allow horticultural industries to be better prepared to respond to future SWD detections.

APVMA permits

Generally, before pesticides are legally allowed to be used in Australia labels or permits need to exist allowing the proposed use pattern. This means that when new pests enter Australia Emergency use permits need to be put in place.

In order to put APVMA permits in place applications must be submitted to the APVMA that address a range of issues including evidence that the pesticide being proposed is effective and that the proposed use will not have residue, environmental, crop safety and operator safety issues. The most straightforward applications for emergency use permits are those where an overseas label specifies a pesticide:crop:rate combination (ie use pattern) that is the same as or less than those used in Australia. If the proposed use pattern is very different than local crop safety and residue trials may need to be established to collect data to support the proposed use pattern.

Throughout this document when making recommendations for possible permit applications the most straightforward solutions have been suggested as these would be the quickest and easiest options to apply for in the event of an incursion of SWD.

Chemical control options used commercially overseas

Various insecticides are used commercially for the management of Spotted Wing Drosophila (SWD) overseas (Hamby and Becher, 2016).

The pesticides used overseas on each crop are presented below, commentary on each pesticide is presented in a separate section. This information has been used to develop recommendations for the most suitable pesticides to consider for future permit applications.

Pesticide options used overseas on figs

SWD can cause significant damage to strawberries overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on figs include:

- *Burkholderia* spp. Strain A396 (refer to page 25)
- Clothianidin (refer to page 29)
- Diazinon (refer to page 37)

None of the three chemicals are currently use on figs in Australia. Therefore, local residue data is likely to be required before permits can be put in place to allow the control of SWD on figs.

Recommendations for SWD control on figs

It is recommended that further research is undertaken to determine suitable control options for SWD on figs.

This may include the development of chemical residue trials to collect data to support future permit applications based on overseas labels.

Pesticide options used overseas on berries

Strawberry

SWD can cause significant damage to strawberries overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on strawberries include:

- Bifenthrin (refer to page 22)
- *Burkholderia* spp. Strain A396 (refer to page 25)
- Cyantraniliprole (refer to page 30)
- Cyantraniliprole + Abamectin (refer to page 32)
- Cypermethrin (refer to page 35)
- Fenpropathrin (refer to page 39)
- Maldison (syn. Malathion) (refer to page 47)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options, only Maldison, Cyantraniliprole and Spinetoram are currently used on strawberries in Australia. Maldison is currently used at comparable rates in Australia to its use overseas for SWD control, while Spinetoram and Cyantraniliprole are used at lower rates in Australia than suitable for SWD control.

Therefore, Maldison would be a relatively east permit application whereas Cyantraniliprole and Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Maldison on Strawberries should be considered.

Rubus berries

SWD can cause significant damage to Rubus berries (raspberries, blackberries, etc.) overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on Rubus berries include:

- Bifenthrin (refer to page 22)
- *Burkholderia* spp. Strain A396 (refer to page 25)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cypermethrin (refer to page 35)
- Maldison (syn. Malathion) (refer to page 47)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)
- Zeta-cypermethrin (refer to page 63)

From the above options only Bifenthrin, Maldison and Spinetoram are currently used on Rubus berries in Australia. Both Bifenthrin and Maldison are currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than that used overseas for SWD control.

Therefore, Bifenthrin and Maldison would be relatively easy permit applications, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Bifenthrin and Maldison on Rubus berries should be considered.

Ribes berries

SWD can cause significant damage to Ribes berries (currants, gooseberry, etc.) overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on Ribes berries include:

- Bifenthrin (refer to page 22)
- *Burkholderia* spp. Strain A396 (refer to page 25)

- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cypermethrin (refer to page 35)
- Fenpropathrin (refer to page 39)
- Maldison (syn. Malathion) (refer to page 47)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options, only Bifenthrin, Maldison and Spinetoram are currently used on Ribes berries in Australia. Maldison is currently used at comparable rates in Australia to the rates used overseas for SWD control on all Ribes berries, while Bifenthrin is used on gooseberries (but not on currants) at comparable rates in Australia to the rates used for SWD control overseas. While, Spinetoram is used at lower rates in Australia than that used overseas for SWD control.

Therefore, Bifenthrin (on gooseberries) and Maldison (on all Ribes berries) would be relatively easy permit applications, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Bifenthrin (on gooseberries) and Maldison (on all Ribes berries) should be considered.

Blueberries

SWD can cause significant damage to Blueberries overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on Blueberries include:

- Acetamiprid (refer to page 19)
- Bifenthrin (refer to page 22)
- *Burkholderia* spp. Strain A396 (refer to page 25)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cypermethrin (refer to page 35)
- Fenpropathrin (refer to page 39)
- Maldison (syn. Malathion) (refer to page 47)
- Methomyl (refer to page 50)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)
- Zeta-cypermethrin (refer to page 63)

From the above options only Bifenthrin, Maldison, Methomyl and Spinetoram are currently used on Blueberries in Australia. Both Bifenthrin and Maldison are currently used at comparable rates in Australia to the rates used overseas for SWD control, while Methomyl and Spinetoram are used at lower rates in Australia than that used overseas for SWD control.

Therefore, Bifenthrin and Maldison would be relatively easy permit applications, whereas Methomyl and Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Bifenthrin and Maldison on Blueberries should be considered.

Recommendations for SWD control on berry crops

Based on an assessment of overseas SWD control and Australian use patterns it is recommended that a permit application for the use Maldison on Strawberries, Rubus berries, Ribes berries and Blueberries should be considered.

Based on an assessment of overseas SWD control and Australian use patterns it is recommended that a permit application for the use Bifenthrin on Rubus berries, gooseberries and Blueberries should be considered.

Pesticide options used overseas on stone fruit (including cherries)

Apricots

SWD can cause significant damage to apricots overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on apricots include:

- Beta-cyhalothrin (refer to page 20)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cyantraniliprole + Abamectin (refer to page 32)
- Cyclaniliprole (refer to page 34)
- Cypermethrin (refer to page 35)
- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Maldison (syn. Malathion) (refer to page 47)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options only Maldison and Spinetoram are currently used on Apricots in Australia. Maldison is currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than it is used overseas for SWD control.

Therefore, Maldison would be relatively easy permit application, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Maldison on Apricots should be considered.

Cherries

SWD can cause significant damage to cherries overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on cherries include:

- Beta-cyhalothrin (refer to page 20)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cyantraniliprole + Abamectin (refer to page 32)
- Cyclaniliprole (refer to page 34)
- Cypermethrin (refer to page 35)
- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Maldison (syn. Malathion) (refer to page 47)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options only Maldison and Spinetoram are currently used on cherries in Australia. Maldison is currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than it is used overseas for SWD control.

Therefore, Maldison would be relatively easy permit application, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Maldison on cherries should be considered.

Plums

SWD can cause significant damage to plums overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on plums include:

- Beta-cyhalothrin (refer to page 20)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cyantraniliprole + Abamectin (refer to page 32)
- Cyclaniliprole (refer to page 34)
- Cypermethrin (refer to page 35)
- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Maldison (syn. Malathion) (refer to page 47)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options only Maldison and Spinetoram are currently used on plums in Australia. Maldison is currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than it is used overseas for SWD control.

Therefore, Maldison would be relatively easy permit application, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Maldison on plums should be considered.

Nectarines

SWD can cause significant damage to nectarines overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on nectarines include:

- Beta-cyhalothrin (refer to page 20)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Cyantraniliprole (refer to page 30)
- Cyantraniliprole + Abamectin (refer to page 32)
- Cyclaniliprole (refer to page 34)
- Cypermethrin (refer to page 35)
- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Maldison (syn. Malathion) (refer to page 47)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options only Maldison and Spinetoram are currently used on nectarines in Australia. Maldison is currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than it is used overseas for SWD control.

Therefore, Maldison would be relatively easy permit application, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Maldison on nectarines should be considered.

Peaches

SWD can cause significant damage to peaches overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on peaches include:

- Beta-cyhalothrin (refer to page 20)
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media (refer to page 27)
- Clothianidin (refer to page 29)
- Cyantraniliprole (refer to page 30)
- Cyantraniliprole + Abamectin (refer to page 32)

- Cyclaniliprole (refer to page 34)
- Cypermethrin (refer to page 35)
- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Maldison (syn. Malathion) (refer to page 47)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)

From the above options only Clothianidin, Maldison and Spinetoram are currently used on peaches in Australia. Clothianidin and Maldison are both currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than it is used overseas for SWD control.

Therefore, Clothianidin and Maldison would be relatively easy permit applications, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Clothianidin and Maldison on peaches should be considered.

Recommendations for SWD control on stone fruit

Based on an assessment of overseas SWD control and Australian use patterns it is recommended that a permit application for the use Maldison on apricots, cherries, nectarines, peaches and plums should be considered.

Based on an assessment of overseas SWD control and Australian use patterns it is recommended that a permit application for the use Clothianidin on peaches should be considered.

Pesticide options used overseas on grapes

SWD can cause significant damage to grapes overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on grapes include:

- Beta-cyhalothrin (refer to page 20)
- Cyclaniliprole (refer to page 34)
- Cypermethrin (refer to page 35)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Maldison (syn. Malathion) (refer to page 47)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)
- Zeta-cypermethrin (refer to page 63)

From the above options only Maldison and Spinetoram are currently used on grapes in Australia. Maldison is currently used at comparable rates in Australia to the rates used overseas for SWD control, while Spinetoram is used at lower rates in Australia than it is used overseas for SWD control.

Therefore, Maldison would be relatively easy permit application, whereas Spinetoram may require additional supporting data before a permit can be put in place.

Based on this assessment it is recommend that a permit application for the use Maldison on grapes should be considered.

Recommendations for SWD control on grapes

Based on an assessment of overseas SWD control and Australian use patterns it is recommended that a permit application for the use Maldison on grapes should be considered.

Pesticide options used overseas on Pome fruit

Apples

SWD can cause damage to apples overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on apples include:

- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)
- Beta-cyhalothrin (refer to page 20)

From the above options only Spinetoram is currently used on apples in Australia. However, Spinetoram is used at lower rates in Australia than it is used overseas for SWD control. Therefore, Spinetoram may require additional supporting data before a permit can be put in place allowing its use for SWD control.

Pears

SWD can cause damage to pears overseas. In order to manage the pest various commercial pesticides are used. Pesticides labelled for SWD control on pears include:

- Esfenvalerate (refer to page 38)
- Fenpropathrin (refer to page 39)
- Imidacloprid + Cyfluthrin (refer to page 43)
- Phosmet (refer to page 51)
- Spinetoram (refer to page 56)
- Spinosad (refer to page 59)
- Beta-cyhalothrin (refer to page 20)

From the above options only Spinetoram and Spinosad are currently used on pears in Australia. However, both are used at lower rates in Australia than it is used overseas for SWD control. Therefore, Spinetoram and Spinosad may require additional supporting data before a permit can be put in place allowing its use for SWD control.

Recommendations for SWD control on pome fruit

It is recommended that further research is undertaken to determine suitable control options for SWD on apples and pears. This may include the development of chemical residue trials to collect data to support future permit applications based on overseas labels.

Pesticide options used overseas on other host crops

SWD can impact a number of other crops including citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), kiwi, pomegranate and tropical/sub-tropical species (e.g. guava and feijoa). Pesticide control options are available for these crops overseas (Table 1). However, none of these options are used in Australia at suitable rates for SWD control. Therefore, these pesticides would require additional supporting data before a permit can be put in place allowing their use for SWD control.

Table 1 Pesticide options used overseas on other host crops

CROP	CLOTHIANIDIN		FENPROPATHRIN		SPINETORAM		SPINOSAD	
	Used overseas	Used in Australia	Used overseas	Used in Australia	Used overseas	Used in Australia	Used overseas	Used in Australia
capsicum			Yes	Not used			Yes	Not used
chili			Yes	Not used				
citrus,			Yes	Not used				

CROP	CLOTHIANIDIN		FENPROPATHRIN		SPINETORAM		SPINOSAD	
	Used overseas	Used in Australia	Used overseas	Used in Australia	Used overseas	Used in Australia	Used overseas	Used in Australia
eggplant			Yes	Not used			Yes	Not used
kiwi					Yes	Yes – lower rate than used overseas for SWD control		
pomegranate	Yes	Not used						
tomato			Yes	Not used			Yes	Not used
Tropical and sub-tropical fruit (wide range including feijoa, avocado, guava, passionfruit)			Yes	Not used				

Recommendations for SWD control on other host crops

It is recommended that further research is undertaken to determine suitable control options for SWD on citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), kiwi, pomegranate and tropical/sub-tropical species (e.g. guava and feijoa). This may include the development of chemical residue trials to collect data to support future permit applications based on overseas labels.

Active constituents used to control SWD overseas

Commentary on the effectiveness of the chemicals and the similarity between overseas and Australian use patterns is presented below. This information will assist in identifying suitable pesticides and providing supporting information for the development of emergency use permits that can be put in place should an incursion of Spotted wind drosophila occur in the future.

Appendix 1 provides a summary of the effectiveness, data required for permit applications and impact on beneficial organisms. This information together with other information in the document can be used to develop future permit applications.

Acetamiprid

Mode of Action and Overview

Acetamiprid is classified as a Neonicotinoid (MOA 4A). It is a systemic insecticide that is reported to provide 'fair' control of SWD overseas (University of Connecticut 2018a; b). Acetamiprid is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Blueberry	United States (special label, Mine, Maryland, Michigan and New Jersey only)	Assail 30SG (30% a.i) is used at 5.3 oz/acre (371.3 g (111.4 g a.i)/ha) in sufficient water to ensure full coverage Label says up to 5 applications per year at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Acetamiprid's registered use overseas suggests that it has some efficacy against SWD. Blueberry trials undertaken in the United States have shown that Acetamiprid can be effective at controlling SWD for up to 5 days after application, but that Maldison and Bifenthrin provided superior adult control at 3 and 5 days after treatment (Van Timeren and Isaacs 2013). Similarly, Beers et al., (2011) reported that Acetamiprid provided useful control of larvae but was less effective at controlling adults.

The University of Connecticut (2018a; b) rate Acetamiprid as providing 'fair' control of SWD on berry and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that when Acetamiprid is applied as a foliar spray it is moderately toxic to toxic to most beneficial organisms listed in the manual. Similarly, Acetamiprid is listed as posing a 'moderate' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Acetamiprid is used overseas for SWD control on blueberries but is not used in Australia on blueberries. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the United States use pattern.

Summary

Acetamiprid is used overseas for the control of SWD on blueberries but the pesticide is not used in Australia on blueberries. Therefore, Acetamiprid is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Beta-cyfluthrin

Mode of Action and Overview

Beta-cyfluthrin is classified as a Pyrethroid (MOA 3A). It is a non-systemic insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018a; b). Beta-cyfluthrin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Grapes	United States (special label used in California, Connecticut, Delaware, Idaho, Indiana, Massachusetts, Maryland, Maine, Michigan, Nevada, New Jersey, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington And Wisconsin only)	Baythroid XL (1 lb. a.i/gallon = 120 g a.i/L) is used at 2.4-3.2 fl. oz/acre (175.4-233.8 ml (21-28 ga.i)/ha) Label specifies up to 4 applications per year at 14+ day intervals.	No Australian labels or permits for this crop/insecticide combination	Not applicable
Pome fruit (apples, pears)	United States (special label used in California, Connecticut, Delaware, Idaho, Indiana, Massachusetts, Maryland, Maine, Michigan, Nevada, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington And Wisconsin only)	Baythroid XL (1 lb. a.i/gallon = 120 g a.i/L) is used at 2.4-2.8 fl.oz/acre (175.4-204.6 ml (21-24.6 ga.i)/ha) Label specifies up to 1 application per year	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Stone fruit (apricot, plum, peach, nectarine, cherry)	United States (special label used in California, Connecticut, Delaware, Idaho, Indiana, Massachusetts, Maryland, Maine, Michigan, Nevada, New Jersey, New York, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington And Wisconsin only)	Baythroid XL (1 lb. a.i/gallon = 120 g a.i/L) is used at 2.4-2.8 fl. oz/acre (175.4-204.6 ml (21-24.6 g a.i)/ha) Label specifies up to 2 applications per year at 14+ day intervals.	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Beta-cyfluthrin's registered use overseas suggests that it has some efficacy against SWD. Trials undertaken in the United States have shown that Beta-cyfluthrin and other pyrethroids are effective at controlling adult SWD (Bruck et al., 2011; Haye et al., 2016).

The University of Connecticut (2018a; b) rate Beta-cyfluthrin as providing 'excellent' control of SWD on berry and stone fruit crops.

Impact on beneficial organisms

Beta-cyfluthrin is not specifically listed in the Biobest Side-Effects Manual (2019). However, the manual does list Cyfluthrin which is rated as toxic to most beneficial organisms listed in the manual. Similarly, pyrethroids (including Beta-cyfluthrin) is listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Beta-cyfluthrin is used overseas for SWD control on grapes, stone and pome fruit but is not used in Australia on those crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the United States use pattern.

Summary

Beta-cyfluthrin is used overseas for the control of SWD on the listed crops but the pesticide is not used in Australia on those crops. Therefore, Beta-cyfluthrin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Bifenthrin

Mode of Action and Overview

Bifenthrin is classified as a Pyrethroid (MOA 3A). It is a non-systemic insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018a). Bifenthrin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Black currant	United States	Bifenture 10DF (10% a.i) is used at 5.3-16 oz/acre (371.3-1120.8g (37.1-112.1g a.i)/ha) applied in a minimum of 10 gallons of water/acre (93.5L/ha). Label says up to 5 applications permitted per year and not to apply within 1 days of harvest.	No Australian labels or permits for this crop/insecticide combination	Not applicable
Blueberry	Canada (British Colombia only)	Capture 240 (240 g a.i/L) is used at 300-450ml (72-108 g a.i)/ha in a minimum of 100L/ha Label says up to 2 applications per year at 7+ day intervals	PER84972 permits 100 g a.i/L products to be used on blueberry at 600ml (60 g a.i)/ha.	Overseas rates greater than Australian rate.
Blueberry	United States	Bifenture 10DF (10% a.i) is used at 5.3-16 oz/acre (371.3-1120.8g (37.1-112.1g a.i)/ha) applied in a minimum of 10 gallons of water/acre (93.5L/ha). Label says up to 5 applications permitted per year and not to apply within 1 days of harvest	PER84972 permits 100 g a.i/L products to be used on blueberries at 600ml (60 g a.i)/ha.	Lower overseas rates comparable to Australian rate
Cane berries (raspberry, blackberry	United States	Bifenture 10DF (10% a.i) is used at 8-16 oz/acre (560.4-1120.8 g	PER84972 permits 100 g a.i/L products to be	Lower overseas rates comparable to Australian rate.

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		(56-112.1 g a.i)/ha) applied in a minimum of 50 gallons of water/acre (467.7L/ha). Label says up to 2 applications/year and not to apply within 3 days of harvest.	used on *Rubus* spp. at 600ml (60 g a.i)/ha.	
Gooseberries	United States	Bifenture 10DF (10% a.i) is used at 5.3-16 oz/acre (371.3-1120.8g (37.1-112.1g a.i)/ha) applied in a minimum of 10 gallons of water/acre (93.5L/ha). Label says up to 5 applications permitted per year and not to apply within 1 days of harvest.	PER84972 permits 100 g a.i/L products to be used on *Ribes* spp. (excluding currents) at 600ml (60 g a.i)/ha.	Lower overseas rates comparable to Australian rate for Ribes spp. excluding currents (ie gooseberries)
Red currant	United States	Bifenture 10DF (10% a.i) is used at 5.3-16 oz/acre (371.3-1120.8g (37.1-112.1g a.i)/ha) applied in a minimum of 10 gallons of water/acre (93.5L/ha). Label says up to 5 applications permitted per year and not to apply within 1 days of harvest.	No Australian labels or permits for this crop/insecticide combination	Not applicable
Strawberry	United States	Bifenture 10DF (10% a.i) is used at 6.4-32 oz/acre (448.3-2241.7g	No Australian labels or permits for this	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		(44.8-224.2g a.i)/ha) applied in a minimum of 50 gallons of water/acre (467.7L/ha). Label says multiple applications are permitted per year at 7-14 day intervals.	crop/insecticide combination	

Efficacy against SWD

Bifenthrin's registered use overseas suggests that it has some efficacy against SWD. Trials undertaken in the United States have shown that Bifenthrin and other pyrethroids are effective at controlling adult SWD (Bruck et al., 2011; Haye et al., 2016).

The University of Connecticut (2018a) rate Bifenthrin as providing 'excellent' control of SWD on berry crops.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) rates Bifenthrin as toxic to most beneficial organisms listed in the manual. Similarly, Pyrethroids (including Bifenthrin) are listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Bifenthrin is used overseas for SWD control on blueberries, ribes berries, rubus berries and strawberries and is used in Australia gooseberry, Rubus berries and blueberries at greater rates than it is used overseas for SWD control. This means that no additional data is likely to be required to support a future permit application based on the United States use pattern on gooseberry, Rubus berries and blueberries. However, additional data would be required to support the overseas use pattern on currents.

Summary

Bifenthrin is used overseas under labels for the control of SWD on the above crops. Based on a comparison of overseas and Australian use patterns Bifenthrin appears to be used at similar rates in Australia to control established pests as it is used overseas to control SWD on several crops. Therefore, Bifenthrin is considered suitable for management of SWD on raspberries, blackberries, blueberries and gooseberries, and a permit application of the use of Bifenthrin on these crops should be considered in the future.

Burkholderia spp. Strain A396

Mode of Action and Overview

Burkholderia spp. Strain A396 does not have a classified mode of action (MOA UK). It is a non-systemic insecticide that is reported to provide only 'suppression' of SWD overseas (University of Connecticut 2018a). *Burkholderia* spp. Strain A396 is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (blueberry, red currant, black currant, gooseberry)	United States	Venerate (94.46% ai[1]) is used at 1-2 quarts/acre (2,338.5-4,677ml (2,209-4,417.9 g a.i)/ha) to suppress SWD. Label states that multiple applications are permitted at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cane berries (raspberry and blackberry)	United States	Venerate (94.46% ai) is used at 1-4 quarts/acre (2,338.5-9,354 ml (2,209-8,835.8 g a.i)/ha) to suppress SWD. Label states that multiple applications are permitted at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Fig	United States	Venerate (94.46% ai) is used at 2-4	No Australian labels or permits	Not applicable

[1] Contains >1,500 beet armyworm killing units/mg.

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		quarts/acre (4,667-9,354ml (4,417.9-8,835.8 g a.i)/ha) to suppress SWD. Label states that multiple applications are permitted at 7 day intervals	for this crop/insecticide combination	
Strawberry	United States	Venerate (94.46% ai) is used at 2-4 quarts/acre (4,667-9,354ml (4,417.9-8,835.8 g a.i)/ha) to suppress SWD. Label states that multiple applications are permitted at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Burkholderia spp. Strain A396 is registered use overseas suggesting that it has some efficacy against SWD. The University of Connecticut (2018a) rate Burkholderia spp. Strain A396 as providing 'suppression' of SWD on berry crops. No other efficacy data was found.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) doesn't list Burkholderia spp. Strain A396. Marrone Bio Innovations (2018) suggests that it is non-toxic to most beneficial insects

Data requirements for permit applications

Burkholderia spp. Strain A396 is used overseas for SWD control on figs, blueberries, ribes berries, rubus berries and strawberries but is not available in Australia for use on any crops. This means that additional residue and crop safety data is likely to be required to support a future permit application based on the United States use pattern.

Summary

Burkholderia spp. Strain A396 is used overseas for the control of SWD but the pesticide is not used in Australia on the listed crops. Therefore, *Burkholderia* spp. Strain A396 is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Chromobacterium subtsugae Strain PRAA4-1 and spent fermentation media

Mode of Action and Overview

Chromobacterium subtsugae Strain PRAA4-1 does not have a classified mode of action (MOA UK). It is a non-systemic insecticide that is reported to provide 'fair to poor' control of SWD overseas (University of Connecticut 2018b). *Chromobacterium subtsugae* Strain PRAA4-1 is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (red currant, black currant, gooseberry, blueberry)	United States	Grandevo (30% a.i) is used at 2-3lb/acre (2,241.7-3,362.6 g (672.5-1,008.8 g a.i)/ha) Label says to apply with a non-ionic surfactant using a minimum of 100 gallons of water/acre (935.4L/ha). The label allows multiple applications at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cane berries (raspberry, black berry, etc.)	United States	Grandevo (30% a.i) is used at 2-3lb/acre (2,241.7-3,362.6 g (672.5-1,008.8 g a.i)/ha) Label says to apply with a non-ionic surfactant using a minimum of 100 gallons of water/acre (935.4L/ha). The label allows multiple applications at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (apricot, cherry, plum, peach, nectarine, prune_	United States	Grandevo (30% a.i) is used at 3lb/acre (3,362.6 g (1,008.8	No Australian labels or permits for this	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		g a.i)/ha) Label says to apply with a non-ionic surfactant using a minimum of 100 gallons of water/acre (935.4L/ha). The label allows multiple applications at 7 day intervals	crop/insecticide combination	

Efficacy against SWD

Chromobacterium subtsugae Strain PRAA4-1 is registered use overseas suggesting that it has some efficacy against SWD. The University of Connecticut (2018b) rate *Chromobacterium subtsugae* Strain PRAA4-1 as providing 'fair to poor' control of SWD on stone fruit. No other efficacy data was found.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) doesn't list *Chromobacterium subtsugae* Strain PRAA4-1. Biorationals: Ecological Pest Management Database (2019) suggests that its use is not damaging to most beneficial insect populations.

Data requirements for permit applications

Chromobacterium subtsugae Strain PRAA4-1 is used overseas for SWD control on blueberries, ribes berries, rubus berries and stone fruit but is not available in Australia for use on any crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the United States use pattern.

Summary

Chromobacterium subtsugae is used overseas for the control of SWD but the pesticide is not used in Australia on the listed crops. Therefore, *Chromobacterium subtsugae* is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Clothianidin

Mode of Action and Overview

Clothianidin is classified as a Neonicotinoid (MOA 4A). It is a systemic insecticide that is reported to provide 'good' control of SWD overseas (University of Connecticut 2018a). Clothianidin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Fig	United states (Special label for use in California only)	Belay (2.13 lb a.i/gallon (255.2 g a.i/L)) is used at 4-6 fl. oz/acre (292.3-438.5 ml (74.6-111.9 g a.i)/ha) in 100-400 gallons/acre (=935.4-3,741.6L/ha) Label allows up to 2 applications per year	No Australian labels or permits for this crop/insecticide combination	Not applicable
Peach	United states (Special label for use in California only)	Belay (2.13 lb a.i/gallon (255.2 g a.i/L)) is used at 4-6 fl. oz/acre (292.3-438.5 ml (74.6-111.9 g a.i)/ha) in 100-400 gallons/acre (=935.4-3,741.6L/ha) Label allows up to 2 applications per year	Samurai (500g a.i/kg) is used at 40g (20 g a.i)/100L	The concentration used in Australia is greater than that used overseas (based on overseas labels suggested water volumes) to control SWD
Pomegranate	United states (Special label for use in California only)	Belay (2.13 lb a.i/gallon (255.2 g a.i/L)) is used at 4-6 fl. oz/acre (292.3-438.5 ml (74.6-111.9 g a.i)/ha) in 100-400 gallons/acre (=935.4-3,741.6L/ha) Label allows up to 2 applications per year	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Clothianidin is registered use overseas suggesting that it has some efficacy against SWD. The University of Connecticut (2018a) rate Clothianidin as providing 'good' control of SWD on berry crops. Similarly, Cowles et al., 2015) found that Clothianidin was less effective at controlling adult SWD than Spinetoram, Spinosad, Acetamiprid and Maldison but more effective than Imidacloprid and Thiamethoxam.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) has no data on the impact of Clothianidin on beneficial insects. Clothianidin is listed as posing a 'moderate' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Clothianidin is used overseas for SWD control on fig, peach and pomegranate but is not used on figs or pomegranate in Australia. It is however used on peaches at higher rates than it is used overseas for SWD control. This means that no additional data is likely to be required to support a future permit application based on the United States use pattern on peach, but that additional data would be required to support the overseas use pattern on pomegranate and figs.

Summary

Clothianidin is used overseas under labels for the control of SWD on the above crops. Based on a comparison of overseas and Australian use patterns Clothianidin appears to be used at similar rates in Australia to control established pests as it is used overseas to control SWD on peaches but not on figs or pomegranates). Therefore, Clothianidin is considered suitable for management of SWD on peaches, and a permit application of the use of Clothianidin on peaches should be considered in the future.

Cyantraniliprole

Mode of Action and Overview

Cyantraniliprole is classified as a Diamide (MOA 28). It is a systemic insecticide that is reported to provide 'good to excellent' control of SWD overseas (University of Connecticut 2018a; b). Cyantraniliprole is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (blueberry, gooseberry, red currant, black currant)	Canada	Exirel (100 g a.i/L) is used at 1,000-1,500 ml (100-150 g a.i)/ha applied in sufficient water to ensure coverage with a suitable surfactant Label says up to 4 applications at 5+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Bush berries (blueberry, gooseberry, red currant, black currant)	United States	Exirel (0.83 lb a.i/gallon = ~100 g a.i./L) is used at 13.5-20.5 fl.oz/acre (986.6-1498.1 ml (98.66-149.81 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 3 application at 5+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cane berries (raspberry,	Canada	Exirel (100 g a.i/L) is used at 1,000-1,500	No Australian labels or permits	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
blackberry, etc)		ml (100-150 g a.i)/ha applied in sufficient water to ensure coverage with a suitable surfactant Label says up to 4 applications at 5+ day intervals	for this crop/insecticide combination	
Stone fruit (Apricot, cherry, peach, plum, nectarine, prune)	Canada	Exirel (100 g a.i/L) is used at 1,000-1,500 ml (100-150 g a.i)/ha applied in sufficient water to ensure coverage Label says up to 4 applications at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (Apricot, cherry, peach, plum, nectarine, prune)	United States	Exirel (0.83 lb a.i/gallon = ~100 g a.i./L) is used at 13.5-20.5 fl. oz/acre (986.6-1498.1 ml (98.66-149.81 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 3 application at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Strawberry	United States	Exirel (0.83 lb a.i/gallon = ~100 g a.i./L) is used at 13.5-20.5 fl. oz/acre (986.6-1498.1 ml (98.66-149.81 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 3 application at 7+ day intervals	Benevia (100 g a.i/L) is used at up to 750ml (75 g a.i)/ha	Overseas rates greater than Australian rate.

Efficacy against SWD

Cyantraniliprole is registered use overseas suggesting that it has some efficacy against SWD. Cyantraniliprole is reported to provide good control of adults as well as providing larvicidal and ovicidal effects of SWD (Alvarez 2015). The University of Connecticut (2018a; b) rate Cyantraniliprole as providing 'good to excellent' control of SWD on berry and stone fruit crops.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) has no data on the impact of Cyantraniliprole on beneficial insects. Cyantraniliprole is listed as posing a 'moderate' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Cyantraniliprole is used overseas for SWD control on stone fruit, strawberries, blueberries, Rubus berries and Ribes berries. but is not used on these crops in Australia, except for strawberries where it is used at lower rates in Australia than it is approved for use for SWD control overseas. This means that additional residue and crop safety data would likely be required to support SWD control at the overseas rates on the listed crops.

Summary

Cyclaniliprole is used overseas for the control of SWD but the pesticide is not used in Australia on the listed crops (with the exception of strawberries where it is used in Australia but at a lower rate than it is used overseas for the control of SWD). Therefore, Cyclaniliprole is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Cyantraniliprole + Abamectin

Mode of Action and Overview

Cyantraniliprole is classified as a Diamide (MOA 28), while Abamectin is an Avermectin (MOA 6), meaning this product has two modes of action. Both actives are systemic insecticides and the combination is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018b). Cyantraniliprole+ Abamectin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
strawberry	United States	Minecto Pro (1.13 lb a.i Cyantraniliprole + Abamectin 0.24 lb a.i/gallon (=135.4 g a.i Cyantraniliprole + 28.8 g a.i Abamectin/L)) is used at 10 fl. oz/acre (730.8ml (98.8 g a.i Cyantraniliprole + 21 g a.i Abamectin)/ha) applied in a minimum of 50 gallons/acre (467.7 L/ha). Label allows up to 2 applications/ year.	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
stone fruit (Apricot, cherry, peach, plum, nectarine, prune)	United States	Minecto Pro (1.13 lb a.i Cyantraniliprole + Abamectin 0.24 lb a.i/gallon (=135.4 g a.i Cyantraniliprole + 28.8 g a.i Abamectin/L)) is used at 10-12 fl. oz/acre (730.8 – 876.9ml (98.8-118.7 g a.i Cyantraniliprole + 21-25.3 g a.i Abamectin)/ha) applied in a minimum of 40 gallons/acre (374.2 L/ha). Label allows up to 2 applications/ year.	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Cyantraniliprole + Abamectin is registered use overseas suggesting that it has some efficacy against SWD. Cyantraniliprole is reported to provide good control of adults as well as providing larvicidal and ovicidal effects of SWD (Alvarez 2015). Abamectin has been reported to provide some ovicidal activity against SWD but displayed limited effectiveness on adults (Schlesner et al., 2017).

The University of Connecticut (2018b) rate Cyantraniliprole + Abamectin as providing 'excellent' control of SWD on stone fruit crops.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) has no data on the impact of Cyantraniliprole combined with Abamectin on beneficial insects. Both Cyantraniliprole and Abamectin are listed as posing a 'moderate' impact, on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Cyantraniliprole + Abamectin is used overseas for SWD control on stone fruit and strawberries but is not available as a combination in Australia. This means that a significant amount of data would likely be required to support SWD control at the overseas rates on the listed crops.

Summary

Cyantraniliprole + Abamectin is used overseas for the control of SWD but the pesticide is not used in Australia on the listed crops. Therefore, Cyantraniliprole + Abamectin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Cyclaniliprole

Mode of Action and Overview

Cyclaniliprole is a relatively new pesticide that is classified as a Diamide (MOA 28). It is a systemic insecticide that is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Grapes	Canada	Harvanta 50SL (50 g a.i/L) is used at 1,200-1,600ml (60-80 g a.i)/ha applied in 935-1,400 L water/ha Label says up to 3 applications at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (Apricot, cherry, peach, plum, nectarine, prune)	Canada	Harvanta 50SL (50 g a.i/L) is used at 1,200-1,600ml (60-80 g a.i)/ha applied in 935-1,870 L water/ha Label says up to 5 applications at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Cyclaniliprole is registered for use overseas suggesting that it has some efficacy against SWD. The University of Connecticut (2018a; b) did not assess the efficacy of Cyclaniliprole on berry or stone fruit crops.

Trials undertaken in the United States have shown that Cyclaniliprole provided effective control adult SWD (Wise et al., 2015 a; b). with control being similar to Cyantraniliprole, Methomyl, Phosmet and Spinetoram and Zeta-cypermethrin (which according to University of Connecticut (2018a; b) provided 'excellent' to 'good to excellent' control of SWD.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) does not list Cyclaniliprole in the manual. However, the Australian Cyclaniliprole label notes that it is toxic to beneficial organisms (Teppan 50SL).

Data requirements for permit applications

Cyclaniliprole is used overseas for SWD control on grapes and stone fruit but it is not used in Australia on those crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the United States use.

Summary

Cyclaniliprole is used overseas for the control of SWD but the pesticide is not used in Australia on the listed crops. Therefore, Cyclaniliprole is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Cypermethrin

Mode of Action and Overview

Cypermethrin is classified as a Pyrethroid (MOA 3A). It is a non-systemic insecticide that is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (blue berry, gooseberry, red currant, black currant)	Canada	Mako (407 g a.i/L) is used at 150ml (61.05 g a.i)/ha for **suppression** of SDW Label says to only make one application per year. Label says not to apply within 2 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cane berries (raspberry, blackberry, etc)	Canada	Mako (407 g a.i/L) is used at 150ml (61.05 g a.i)/ha for **suppression** of SDW Label says to only make one application per year. Label says not to apply within 2 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Grape	Canada	Mako (407 g a.i/L) is used at 150ml (61.05 g a.i)/ha for **suppression** of SDW Label says to only make one application per year. Label says not to apply within 6 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Stone fruit (Apricot, cherry, peach, plum, nectarine, prune)	Canada	Mako (407 g a.i/L) is used at 150ml (61.05 g a.i)/ha for **suppression** of SDW Label says to only make one application per year. Label says not to apply within 2 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Strawberry	Canada	Mako (407 g a.i/L) is used at 150ml (61.05 g a.i)/ha for **suppression** of SDW Label says to only make one application per year. Label says not to apply within 2 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Cypermethrin is registered for the suppression of SWD overseas suggesting that it has limited efficacy against SWD.

The University of Connecticut (2018a; b) did not assess the efficacy of Cypermethrin on berry or stone fruit crops.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) rates Cypermethrin as 'toxic' towards the beneficial insects listed in the manual. Similarly, Cypermethrin is listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Cypermethrin is used overseas for SWD control on grapes, berries and stone fruit but it is not used in Australia on those crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Cypermethrin is used overseas for the suppression of SWD but the pesticide is not used in Australia on the listed crops. Therefore, Cypermethrin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Diazinon

Mode of Action and Overview

Diazinon is classified as an Organophosphate (MOA 1B). It is a non-systemic insecticide that is reported to provide 'good' control of SWD overseas (University of Connecticut 2018a; b). Diazinon is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Fig	United states	Diazinon AG500 (4lb a.i/gallon = 479.3 g a.i/L) is used at 1 pint/100 gallons (125ml (59.9 g a.i)/100L) applied at 100 gallons/acre (=935.4L/ha) (=560.42 g a.i/ha) to control *Drosophila* spp. Label says that only one application is permitted per year.	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Diazinon is registered for the control of SWD overseas suggesting that it has some efficacy against SWD.

The University of Connecticut (2018a; b) rate Diazinon as providing 'good' control of SWD on berry and stone fruit crops.

Impact on beneficial organisms

The Biobest Side-Effects Manual (2019) rates Diazinon as 'toxic' towards most of the beneficial insects listed in the manual.

Data requirements for permit applications

Diazinon is used overseas for SWD control on figs but it is not used on figs in Australia. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use pattern.

Summary

Diazinon is used overseas under labels for the control of SWD on figs in the United States but the pesticide is not used in Australia on figs. Therefore, Diazinon is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Esfenvalerate

Mode of Action and Overview

Esfenvalerate is classified as a Pyrethroid (MOA 3A). It is a non-systemic, contact insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018b). Esfenvalerate is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Apples	United States (Special label used in: Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, West Virginia And Washington only)	Asana (0.66lb a.i/gallon = 80 g a.i/L) is used at 4.8-14.5 fl oz/acre (350.8-1,059.6ml (28.1-84.8 g a.i)/ha) Label says multiple applications permitted each year Label says not to apply within 21 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Pears	United States (Special label used in: Connecticut, Delaware, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, West Virginia And Washington only)	Asana (0.66lb a.i/gallon = 80 g a.i/L) is used at 4.8-14.5 fl oz/acre (350.8-1,059.6ml (28.1-84.8 g a.i)/ha) Label says multiple applications permitted each year Label says not to apply within 28 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (plums apricot, cherry,	United States (Special label used in: Connecticut,	Asana (0.66lb a.i/gallon = 80 g a.i/L) is used at 4.8-	No Australian labels or permits for this	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
peach, nectarine)	Delaware, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Vermont, Virginia, West Virginia And Washington only)	14.5 fl oz/acre (350.8-1,059.6ml (28.1-84.8 g a.i)/ha) Label says multiple applications permitted each year Label says not to apply within 14 days of harvest	crop/insecticide combination	

Efficacy against SWD

Esfenvalerate's registered use overseas suggests that it has some efficacy against SWD.

The University of Connecticut (2018b) rate Esfenvalerate as providing 'excellent' control of SWD on stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Esfenvalerate is 'toxic' to most beneficial organisms listed in the manual. Similarly, Esfenvalerate is listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Esfenvalerate is used overseas for SWD control on pome and stone fruit but is not used in Australia on those crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Esfenvalerate is used overseas under labels for the control of SWD overseas but the pesticide is not used in Australia on the listed crops. Therefore, Esfenvalerate is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Fenpropathrin

Mode of Action and Overview

Fenpropathrin is classified as a Pyrethroid (MOA 3A). It is a non-systemic insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018a; b). Fenpropathrin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (blueberry, gooseberry, red currant, black currant)	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 16 fl. oz/acre (1,169.2 ml (336.3 g a.i)/ha). Label says that soil should also be treated to kill any insects on fallen fruit	No Australian labels or permits for this crop/insecticide combination	Not applicable
Citrus	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 16-21.33 fl oz/acre (1,169.2-1558.7 ml (336.3-448.3 g a.i)/ha) applied in 50-500 gallons/acre (=467.7-4,677 L/ha) Label says to reapply at 10 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Fruiting vegetables (tomato, capsicum, eggplant, chili)	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L) is used at 10.66 fl oz/acre (779 ml (224 g a.i)/ha) applied in 25 gallons/acre (=233.8L/ha) Label says to reapply at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Grape	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 10.66-21.33 fl oz/acre (779-1558.7 ml (224-448.3 g a.i)/ha) applied in 25 gallons/acre Label says to reapply at 7 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Pome fruit (apple, pear, quince etc)	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 16-21.33 fl oz/acre (1,169.2-1558.7 ml (336.3-448.3 g a.i)/ha) applied in sufficient water to ensure coverage Label says to reapply at 10 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (apricot, cherry, plum, peach, prune, nectarine)	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 10.66-21.33 fl oz/acre (779-1558.7 ml (224-448.3 g a.i)/ha) applied in 100+ gallons/acre (935.4 L/ha) Label says to reapply at 10 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Strawberry	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 16-21.33 fl oz/acre (1,169.2-1558.7 ml (336.3-448.3 g a.i)/ha) applied in 100+ gallons/acre (935.4 L/ha)	No Australian labels or permits for this crop/insecticide combination	Not applicable
Tropical and sub-tropical fruit (wide range including feijoa, avocado, guava, passionfruit)	United states	Danitol (2.4 lb a.i/gallon = 287.6g a.i/L)is used at 16-21.33 fl oz/acre (1,169.2-1558.7 ml (336.3-448.3 g a.i)/ha) applied in 75+ gallons/acre (701.5 L/ha) Label says to reapply at 14+ day	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		intervals		

Efficacy against SWD

Fenpropathrin's registered use overseas suggests that it has some efficacy against SWD.

The University of Connecticut (2018a; b) rate Esfenvalerate as providing 'excellent' control of SWD on berry and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Fenpropathrin is 'toxic' to most beneficial organisms listed in the manual.

Data requirements for permit applications

Fenpropathrin is used overseas for SWD control on a range of fruit crops but is not available in Australia. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Fenpropathrin is used overseas under labels for the control of SWD overseas but the pesticide is not used in Australia on the listed crops. Therefore, Fenpropathrin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Imidacloprid + Cyfluthrin

Mode of Action and Overview

Imidacloprid is classified as a Neonicotinoid (MOA 4A), while Cyfluthrin is a Pyrethroid (MOA 3A), meaning this product has two modes of action. Imidacloprid is a systemic insecticide and Cyfluthrin is a non-systemic insecticide and the combination is reported to provide 'good' control of SWD overseas (University of Connecticut 2018b). Imidacloprid + Cyfluthrin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Grape	United States (special label California, Connecticut, Delaware, Idaho, Indiana, Massachusetts, Maryland, Maine, Michigan, Nevada, New Jersey, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington And Wisconsin only	Leverage 360 (2 lb a.i Imidacloprid + 1 lb a.i Cyfluthrin (=239.7 g a.i Imidacloprid + 119.8g a.i Cyfluthrin/L) is used at 2.4-3.2 fl oz/acre ((175.4-233.8 ml (42-56 g a.i Imidacloprid + 21-28 g a.i Cyfluthrin)/ha). Label states that up to 2 applications are permitted/year at 14+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Pome fruit (apple, pear, quince)	United States (special label California, Connecticut, Delaware, Idaho, Indiana, Massachusetts, Maryland, Maine, Michigan, Nevada, New Jersey, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington And Wisconsin only)	Leverage 360 (2 lb a.i Imidacloprid + 1 lb a.i Cyfluthrin (=239.7 g a.i Imidacloprid + 119.8g a.i Cyfluthrin/L) is used at 2.4-2.8 fl oz/acre (175.4-204.6 ml (42-49 g a.i Imidacloprid + 21-24.5 g a.i Cyfluthrin)/ha). Label states that only one application is permitted per year	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (apricot, cherry, plum,	United States (special label	Leverage 360 (2 lb a.i Imidacloprid + 1	No Australian labels or permits	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
nectarine, peach, prune)	California, Connecticut, Delaware, Idaho, Indiana, Massachusetts, Maryland, Maine, Michigan, Nevada, New Jersey, Ohio, Oregon, Pennsylvania, Rhode Island, Utah, Vermont, Virginia, Washington And Wisconsin only)	lb a.i Cyfluthrin (=239.7 g a.i Imidacloprid + 119.8g a.i Cyfluthrin/L) is used at 2.4-2.8fl oz/acre (175.4-204.6 ml (42-49 g a.i Imidacloprid + 21-24.5 g a.i Cyfluthrin)/ha). Label states that up to 2 applications are permitted/year at 14+ day intervals	for this crop/insecticide combination	

Efficacy against SWD

Imidacloprid + Cyfluthrin's registered use overseas suggests that it has some efficacy against SWD.

The University of Connecticut (2018 b) rate Imidacloprid + Cyfluthrin as providing 'good' control of SWD on stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Imidacloprid is 'non-toxic to 'moderately toxic' while Cyfluthrin is listed as 'toxic' to most beneficial organisms listed in the manual. Similarly, Imidacloprid is listed as posing a 'moderate' impact and Cyfluthrin is listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Imidacloprid + Cyfluthrin is used overseas for SWD control on grape, pome and stone fruit but is this combination of pesticides is not available in Australia. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Imidacloprid + Cyfluthrin is used overseas under labels for the control of SWD overseas but the pesticide is not used in Australia on the listed crops. Therefore, Imidacloprid + Cyfluthrin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Lambda cyhalothrin

Mode of Action and Overview

Lambda cyhalothrin is classified as a Pyrethroid (MOA 3A). It is a non-systemic insecticide that is reported to provide 'good to excellent' control of SWD overseas (University of Connecticut 2018b). Lambda cyhalothrin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Cherry (sweet and sour)	United States (special label, California, Indiana, Michigan, Montana, Oregon, Pennsylvania, Utah, Wisconsin, Washington)	Warrior II (2.08 lb a.i/gallon (=249.2 g a.i/L)) is used at 2.56 fl.oz./acre (187.1 g (46.6 ga.i)/ha). The label allows up to 5 applications/year at 5+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Lambda cyhalothrin is registered for use overseas suggesting that it has some efficacy against SWD.

The University of Connecticut (2018 b) rate Lambda cyhalothrin as providing 'good to excellent' control of SWD on stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Lambda cyhalothrin is 'toxic' to most beneficial organisms listed in the manual. Similarly, Lambda cyhalothrin is listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Lambda cyhalothrin is used overseas for SWD control on cherries but is not used in Australia on cherries. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Lambda cyhalothrin is used overseas under labels for the control of SWD but the pesticide is not used in Australia on cherries. Therefore, Lambda cyhalothrin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Lambda cyhalothrin + Thiamethoxam

Mode of Action and Overview

Lambda cyhalothrin is classified as a Pyrethroid (MOA 3A), while Thiamethoxam is classified as a Neonicotinoid (4A). Lambda cyhalothrin is a non-systemic insecticide and Thiamethoxam is a systemic insecticide. The combination is reported to provide 'good' control of SWD overseas (University of Connecticut 2018b). Lambda cyhalothrin + Thiamethoxam is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Cherry (sweet and sour)	United States (special label, Oregon and Washington only)	Endigo ZC (1.18 lb a.i Thiamethoxam + 0.88 lb a.i Lambda-cyhalothrin/gallon = 141.4 g a.i Thiamethoxam + 105.4 g a.i Lambda-cyhalothrin/L) is used at 5-6 fl.oz./acre (365.4-438.5 ml (51.66-62 g a.i Thiamethoxam + 38.5-46.2 g a.i Lambda-cyhalothrin)/ha Label says multiple applications permitted at 7+ day intervals.	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Lambda cyhalothrin + Thiamethoxam is registered for use overseas suggesting that it has some efficacy against SWD. The University of Connecticut (2018 b) rate Lambda cyhalothrin + Thiamethoxam as providing 'good' control of SWD on stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that both Lambda cyhalothrin and, Thiamethoxam are listed as 'toxic' to most beneficial organisms listed in the manual. Similarly, Lambda cyhalothrin is listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018). This suggests that both actives are potentially damaging to beneficial insects.

Data requirements for permit applications

Lambda cyhalothrin + Thiamethoxam is used overseas for SWD control on cherries but is only used as a seed dressing in Australia. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Lambda cyhalothrin + Thiamethoxam is used overseas under labels for the control of SWD but the pesticide is not used in Australia on cherries. Therefore, Lambda cyhalothrin + Thiamethoxam is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Maldison (syn. Malathion)

Mode of Action and Overview

Maldison (known overseas as Malathion) is classified as an Organophosphate (MOA 1B). It is a non-systemic insecticide that is reported to provide 'good' control of SWD overseas (University of Connecticut 2018a; b). Maldison is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Blackberry	Canada	Malathion 85E (85% a.i) is used at 1,000ml (850 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Australian and overseas use patterns comparable
Blueberry	Canada	Malathion 85E (85% a.i) is used at 1,000ml (850 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Australian and overseas use patterns comparable
Blueberry	United States (special labels: Delaware, Florida, Georgia, Indiana, Massachusetts, Maryland, Maine, Michigan, Mississippi, North Caroline, New Hampshire, New Jersey, Oregon, Pennsylvania, Virginia, Washington only)	Malathion 8F (8lb a.i/gallon (958.6 g a.i/L)) is used in is used in various states of the United States at 2.5pints/acre (2,925.11ml (2,804 g a.i)/ha) Label allows up to 2 applications per year at 7+ day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Comparison not possible without knowing minimum water volumes used overseas or minimum volumes used per hectare in Australia pm this crop

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Cane berries (raspberry and blackberry, etc.)	United States (Special labels: Georgia, Indiana, Massachusetts, Maryland, Maine, Michigan, North Caroline, New Hampshire, New Jersey, Oregon, Pennsylvania, Virginia only)	Malathion 8F (8lb a.i/gallon (958.6 g a.i/L)) is used in various states of the United States at 2 pints/acre (2,338.5 ml (2,241.7 g a.i)/ha. Label allows up to 4 applications per year at 7+ day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Comparison not possible without knowing minimum water volumes used overseas or minimum volumes used per hectare in Australia pm this crop
Currants	Canada	Malathion 85E (85% a.i) is used at 1,000ml (850 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Australian and overseas use patterns comparable
Gooseberry	Canada	Malathion 85E (85% a.i) is used at 1,000ml (850 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Australian and overseas use patterns comparable
Grape	Canada	Malathion 85E (85% a.i) is used at 880ml (748 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 1 application per year	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 4 applications/year at 7+ day intervals	Australian and overseas use patterns comparable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Raspberry	Canada	Malathion 85E (85% a.i) is used at 1,000ml (850 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Australian and overseas use patterns comparable
Stone fruit (cherry (sweet and sour), apricot, nectarine, peach, plum, prune)	Canada	Malathion 85E (85% a.i) is used at 610-855ml (518.5-726.75 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 4 applications/year at 7+ day intervals	Australian and overseas use patterns comparable
Strawberry	Canada	Malathion 85E (85% a.i) is used at 1,000ml (850 g a.i)/1,000L water, applied at 1,000L/ha. The label allows 2 applications per year at 7-10 day intervals	Fyfanon 440 EW (440 g a.i/kg) is used at 140-230ml (61.6-101.2 g a.i)/100L Label allows up to 6 applications/year at 7+ day intervals	Australian and overseas use patterns comparable

Efficacy against SWD

Maldison is registered for use overseas suggesting that it has some efficacy against SWD.

The University of Connecticut (2018a; b) rate Maldison as providing 'good' control of SWD on berries and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Maldison is 'toxic' to most beneficial organisms listed in the manual.

Data requirements for permit applications

Maldison is used overseas for SWD control on a range of crops and is used in Australia on blueberries, grapes, ribes berries, rubus berries, stone fruit and strawberries. This means that no additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Maldison is used overseas under labels for the control of SWD on the above crops. Based on a comparison of overseas and Australian use patterns Maldison appears to be used at similar rates in Australia to control established pests as it is used overseas to control SWD. Therefore, Maldison is considered suitable for management of SWD on blackberry, blueberry, currants, gooseberry, grape, raspberry, stone fruit (cherry (sweet and sour), apricot, nectarine, peach, plum, prune) and strawberry and a permit application of the use of Maldison on the listed crops should be considered in the future.

Methomyl

Mode of Action and Overview

Methomyl is classified as a Carbamate (MOA 1A). It is a systemic insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018a; b). Methomyl is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
blueberries	United states	Lannate LV (2.4 lb a.i/gallon (=287.6g a.i/L) is used at 1.5-3 pints/acre (1,753.9-3,507.7 ml (504.4-1,008.8 g a.i)/ha) applied with sufficient water to ensure thorough coverage. Label suggests a minimum of 50 gallons/acre (467.7L/ha). Label states that up to 4 applications are permitted/year.	Agsure Methomyl 225 (225 g a.i/L) and similar products are used at 100ml (22.5 g a.i)/100L.	Australian rate is significantly lower than the rates used overseas (based on the minimum water volumes noted on the overseas label)

Efficacy against SWD

Methomyl is registered for use overseas suggesting that it has some efficacy against SWD.

The University of Connecticut (2018a; b) rate Methomyl as providing 'excellent' control of SWD on berries and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Methomyl is 'toxic' to most beneficial organisms listed in the manual.

Data requirements for permit applications

Methomyl is used overseas for SWD control on blueberries and is used in Australia on blueberries but at lower rates than it is used for SWD control overseas. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Methomyl is used overseas under labels for the control of SWD on blueberries. Methomyl is used in Australia on blueberries but at a lower rate than it is used overseas for the control of SWD. Therefore, Methomyl is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Phosmet

Mode of Action and Overview

Phosmet is classified as an Organophosphate (MOA 1B). It is a non-systemic insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018a; b). Phosmet is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Apples	Canada	Imidan 70WP (70% a.i) is used at 2,680 g (1,876 g a.i)/ha applied in sufficient water to ensure thorough coverage. Label says up to 5 applications at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Apples	United States	Imidan 70W (70% a.i) is used at 2.125-5.75 lb/acre (2,381.8-6444.9 g (1,667.3-4,511.4 g a.i)/ha) applied in sufficient water to ensure thorough coverage Label says up to 3 applications per year	No Australian labels or permits for this crop/insecticide combination	Not applicable
Apricots	United States	Imidan 70W (70% a.i) is used at 2.125-4.25lb/acre (2,381.8-4,763.6g (1,667.3-3,334.5 g a.i)/ha) applied in sufficient water to ensure thorough coverage	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		Label says up to 3 applications per year		
Blueberries	Canada	Imidan 70WP (70% a.i) is used at 1,600 g (1,120 g a.i)/ha applied in 1,000L water/ha Label says up to 2 applications/season up to 15 days before harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Blueberries	United States	Imidan 70W (70% a.i) is used at 1.33lb/acre (1,490.7 g (1,043.5 g a.i)/ha) applied in sufficient water to ensure thorough coverage Label says up to 5 applications per year Label says not to treat within 3 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cherries	Canada	Imidan 70WP (70% a.i) is used at 2,680 g (1,876 g a.i)/ha applied in sufficient water to ensure thorough coverage. Label says up to 4 applications at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Grapes	Canada	Imidan 70WP (70% a.i) is used at 1360- 2,200 g (1,540 g a.i)/ha applied in sufficient water to ensure thorough coverage.	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		Label says up to 3 dp not apply within 14 days of harvest		
Grapes	United States	Imidan 70W (70% a.i) is used at 1.33-2.125lb/acre (1,490.7-2,381.8 g (1,043.5-1,667.3 g a.i)/ha) applied in sufficient water to ensure thorough coverage Label says up to 3 applications per year. Label says not to harvest within 7 days of treatment	No Australian labels or permits for this crop/insecticide combination	Not applicable
Nectarine and peaches	United States	Imidan 70W (70% a.i) is used at 2.125-4.25lb/acre (2,381.8-4,763.6g (1,667.3-3,334.5 g a.i)/ha) applied in sufficient water to ensure thorough coverage Label says up to 3 applications per year. Label says up not to harvest within 7 days of treatment	No Australian labels or permits for this crop/insecticide combination	Not applicable
Peaches	Canada	Imidan 70WP (70% a.i) is used at 2,680 g (1,876 g a.i)/ha applied in sufficient water to ensure thorough coverage. Label says up to 4 applications do not apply within 14 days	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		of harvest		
Pears	Canada	Imidan 70WP (70% a.i) is used at 2,680 g (1,876 g a.i)/ha applied in sufficient water to ensure thorough coverage. Label says up to 5 applications at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Pears	United States	Imidan 70W (70% a.i) is used at 2.125-5.75 lb/acre (2,381.8-6444.9 g (1,667.3-4,511.4 g a.i)/ha) applied in sufficient water to ensure thorough coverage Label says up to 3 applications per year	No Australian labels or permits for this crop/insecticide combination	Not applicable
Plums	Canada	Imidan 70WP (70% a.i) is used at 2,680 g (1,876 g a.i)/ha applied in sufficient water to ensure thorough coverage. Label says up to 3 applications do not apply within 14 days of harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Plums and prunes	United States	Imidan 70W (70% a.i) is used at 2.125-4.25lb/acre (2,381.8-4,763.6g (1,667.3-3,334.5 g a.i)/ha) applied in sufficient water to ensure thorough coverage	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		Label says up to 3 applications per year. Label says not to harvest within 7 days of treatment		
Sour cherry	United States	Imidan 70W (70% a.i) is used at 2.125lb/acre (2,381.8g (1,667.3 g a.i)/ha) applied in sufficient water to ensure thorough coverage Label says up to 3 applications per year	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Phosmet is registered for use overseas suggesting that it has some efficacy against SWD.

The University of Connecticut (2018a; b) rate Phosmet as providing 'excellent' control of SWD on berries and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Phosmet is 'non-toxic to toxic' to most beneficial organisms listed in the manual.

Data requirements for permit applications

Phosmet is used overseas for SWD control on blueberries, grapes, pome and stone fruit but is not used in Australia on those crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Phosmet is used overseas under labels for the control of SWD but the pesticide is not used in Australia on the listed crops. Therefore, Phosmet is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Spinetoram

Mode of Action and Overview

Spinetoram is classified as a Spinosyn (MOA 5). It is a systemic insecticide that is reported to provide 'good-excellent' control of SWD overseas (University of Connecticut 2018a; b). Spinetoram is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (blueberry, red currant, black currant, gooseberry)	United States	Delegate WG (25% a.i) is used at 3-6 oz/acre (210.15-420.3 g (52.5-105 g a.i)/ha) Label says that up to 6 applications can be made at 6+ day intervals	Success Neo (120 g a.i/L) is used at up to 40ml (4.8 ga.i)/100L. Similarly, PER12927 permits the use of Success Neo at up to 400ml (48 g a.i)/ha	Australian rate is lower than the rates used overseas
Bush berries (blueberry, black currant, red currant, gooseberry, etc)	Canada	Delegate (25% a.i) is used at 315-420g (78.85-105 g a.i)/ha applied in sufficient water to ensure coverage Label says up to 3 applications @ 7 + day intervals. Do not apply within 3 days of harvest	Success Neo (120 g a.i/L) is used at up to 40ml (4.8 ga.i)/100L. Similarly, PER12927 permits the use of Success Neo at up to 400ml (48 g a.i)/ha	Australian rate is lower than the rates used overseas
Cane berries (black berry, raspberry, logan berry)	United States	Delegate WG (25% a.i) is used at 3-6 oz/acre (210.15-420.3 g (52.5-105 g a.i)/ha) Label says that up to 6 applications can be made at 4+ day intervals	Success Neo (120 g a.i/L) is used at up to 40ml (4.8 ga.i)/100L. Similarly, PER12927 permits the use of Success Neo at up to 400ml (48 g a.i)/ha	Australian rate is lower than the rates used overseas
Cherries	Canada	Delegate (25% a.i) is used at 420g (105 g a.i)/ha.	Delegate (250 g a.i/kg) is used at up to 20g (5	Australian rate is lower than the rates used overseas (based

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		Label says up to 3 application/year @ 7+ day intervals) in a minimum of 1,000L/ha Label says to apply at 30, 12 and 5 days prior to harvest	ga.i)/100L	on the minimum water volumes noted on the overseas label)
Grape	United States	Delegate WG (25% a.i) is used at 3-5 oz/acre (210.15-350.25 g (52.5-87.6 g a.i)/ha) Label says that up to 5 applications can be made at 7+ day intervals	Delegate (250 g a.i/kg) is used at up to 10g (2.5 g a.i)/100L	Comparison not possible without knowing minimum water volumes used overseas or minimum volumes used per hectare in Australia pm this crop
Hardy kiwi	United States	Delegate WG (25% a.i) is used at 3-5 oz/acre (210.15-350.25 g (52.5-87.6 g a.i)/ha) Label says that up to 5 applications can be made at 7+ day intervals	Success Neo (120 g a.i/L) is used at up to 20ml (2.4 g a.i)/100L	Comparison not possible without knowing minimum water volumes used overseas or minimum volumes used per hectare in Australia pm this crop
Pome fruit (apple, pear, quince)	United States	Delegate WG (25% a.i) is used at 4.5-7 oz/acre (315.2-490.4 g (78.8-122.6 g a.i)/ha) Label says that up to 4 applications can be made at 7+ day intervals	Delegate (250 g a.i/kg) is used at up to 20g (5 g a.i)/100L	Comparison not possible without knowing minimum water volumes used overseas or minimum volumes used per hectare in Australia pm this crop
Prunes, plums apricot, peach and nectarine	Canada	Delegate (25% a.i) is used at 420g (105 g a.i)/ha	Delegate (250 g a.i/kg) is used at up to 20g (5 g	Australian rate is lower than the rates used overseas (based

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		Label says up to 3 application/year @ 7+ day intervals) in a minimum of 1,000L/ha	a.i)/100L	on the minimum water volumes noted on the overseas label)
Stone fruit (apricot, cherry, nectarine, peach, plum, prune)	United States	Delegate WG (25% a.i) is used at 4.5-7 oz/acre (315.2-490.4 g (78.8-122.6 g a.i)/ha) Label says that up to 4 applications can be made at 7+ day intervals	Delegate (250 g a.i/kg) is used at up to 20g (5 g a.i)/100L	Comparison not possible without knowing minimum water volumes used overseas or minimum volumes used per hectare in Australia pm this crop
Strawberry	Canada	Delegate (25% a.i) is used at 280 g (70 g a.i)/ha applied in sufficient water to ensure coverage Label says up to 3 applications @ 7 + day intervals. Do not apply within 1 day of harvest	Success Neo (120 g a.i/L) is used at up to 40ml (4.8 ga.i)/100L. Similarly, PER12927 permits the use of Success Neo at up to 400ml (48 g a.i)/ha	Australian rate is lower than the rates used overseas

Efficacy against SWD

Spinetoram is registered for use overseas suggesting that it has some efficacy against SWD.

Spinetoram is reported to be effective against Diptera, Lepidoptera, Thysanoptera, and Hemiptera while being less toxic to beneficial insects (Shimokawatoko et al., 2012). The University of Connecticut (2018a; b) rate Spinetoram as providing 'good - excellent' control of SWD on berries and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) has no data on the impact of Spinetoram on the beneficial organisms listed in the manual. Spinetoram is also listed as posing a 'low' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018). However, it should be noted that Spinetoram is reported to have some negative impacts on beneficial Hymenoptera (Shearer et al., 2016).

Data requirements for permit applications

Spinetoram is used overseas for SWD control on blueberries, rubus berries, ribes berries, strawberries, grapes, kiwi, pome and stone fruit but although used in Australia on those crops the Australian rates are significantly lower than those used for SWD control overseas. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Spinetoram is used overseas under labels for the control of SWD on blueberries. Methomyl is used in Australia on Strawberry, Bush berries (blueberry, red currant, black currant, gooseberry), Cane berries (black berry, raspberry, logan berry), Pome fruit (apple, pear, quince), Stone fruit (apricot, cherry, nectarine, peach, plum, prune), kiwi and grapes but at lower rates than Spinetoram is used overseas for the control of SWD. Therefore, Spinetoram is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Spinosad

Mode of Action and Overview

Spinosad is classified as a Spinosyn (MOA 5). It is a systemic insecticide that is reported to provide 'good' control of SWD overseas (University of Connecticut 2018a; b). Spinosad is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Bush berries (blueberry, red currant, black currant, gooseberry)	Canada	Entrust (240 g a.i/L) is used at 334-440 ml (80.2-105.6 g a.i)/ha applied in sufficient water to ensure complete coverage of foliage Label says up to 3 applications per season at 5+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Bush berries (blueberry, red currant, black currant, gooseberry)	United States	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used at 4-6 fl. oz/acre (292.3-438.5 ml (70.2-105.24 g a.i)/ha) applied in sufficient water to ensure complete coverage of foliage Label says up to 6 applications per season at 6+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cane berries (blackberry, raspberry, etc)	Canada	Entrust (240 g a.i/L) is used at 334-440 ml (80.2-105.6 g a.i)/ha applied in sufficient water to ensure complete coverage of foliage	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		Label says up to 3 applications per season at 5+ day intervals		
Cherry	United States (special labels, California, Washington only)	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used in California and Washington at 4.8-6.4 fl. oz./acre (350.8-467.7 ml (84.2-112.2 g a.i)/ha applied in sufficient water to ensure coverage 3 applications at 28, 10 and 3 days before harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cherry	United States (special label, Montana only)	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used in Montana at 4.8-8 fl. oz./acre (350.8-584.6 ml (84.2-140.3 g a.i)/ha) applied in sufficient water to ensure coverage Label says to spray from blush or pink stage at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Cherry	United States (special label, Oregon only)	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used in Oregon at 4-6.4 fl. oz/acre (292.3-467.7 ml (70.2-112.2 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 3 applications per year at 30, 10, 3 days prior to harvest	No Australian labels or permits for this crop/insecticide combination	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Fruiting vegetables (tomato, eggplant, capsicum)	Canada	Entrust (240 g a.i/L) is used at 364 ml (87.4 g a.i)/ha applied in sufficient water to ensure complete coverage of foliage Label says up to 3 applications per season at 7-10 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Grape	Canada	Entrust (240 g a.i/L) is used at 364 ml (87.36 g a.i)/ha applied in sufficient water to ensure complete coverage of foliage Label says up to 3 applications per season at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Grapes	United States (special label, all states except Texas)	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used at 4-8 fl. oz/acre (292.3-584.6 ml (70.2-140.3 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 7 applications at 5+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Pome fruit (apple, pear, quince, etc.)	United States (special label, all states except Texas	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used at 4-10 fl. oz/acre (292.3-730.8 ml (70.2-175.4 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 4 applications per season	PER83085 allows the use of Entrust SC (240 g a.i/L) on pears at 20 ml (4.8 g a.i)/100L	Australian rate lower than the overseas rates used to control SWD

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
		at 7+ day intervals		
Stone fruit (apricot, cherry, peach, nectarine, plum, prune)	Canada	Entrust (240 g a.i/L) is used at 364 ml (87.4 g a.i)/ha applied in 1,000L water/ha Label says 3 applications applied 28, 10 and 3 days before harvest (cherries) for other stone fruit apply up to 3 applications at 7-10 day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Stone fruit (apricot, plum, peach, nectarine)	United States (special label, all states except Texas	Entrust SC (2 lb a./gallon = ~240 g a.i/L) is used at 4-8 fl.oz/acre (292.3-584.6 ml (70.2-140.3 g a.i)/ha) applied in sufficient water to ensure coverage Label says up to 3 applications per season at 7+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable
Strawberry	Canada	Entrust (240 g a.i/L) is used at 292-364 ml (70.1-87.4 g a.i)/ha applied in sufficient water to ensure complete coverage of foliage Label says up to 3 applications per season at 5+ day intervals	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Spinosad is registered for use overseas suggesting that it has some efficacy against SWD.

Spinosad is reported to be effective against Diptera, Lepidoptera, Thysanoptera, and Hemiptera while being less toxic to beneficial insects (Leeuwen et al., 2005). The University of Connecticut (2018a; b) rate Spinosad as providing 'good' control of SWD on berries and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) suggests that Spinosad is 'non-toxic to toxic' to most beneficial organisms listed in the manual. Similarly, papers such as Miles and Eelen (2006) report that Spinosad has a low impact on most beneficial organisms making it suitable for use in Integrated Pest Management (IPM) systems. Spinosad is also listed as posing a 'low' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Spinosad is used overseas for SWD control on, rubus berries, ribes berries, blueberries, fruiting vegetables, grapes, pome fruit, stone fruit, and strawberries is not used in Australia on most of the listed crops, with the exception of pears where it is used at a lower rate than it is used for SWD control overseas. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Spinosad is used overseas under labels for the control of SWD but the pesticide is not used in Australia on most of the listed crops, with the exception of pears where it is used at a lower rate than it is used for SWD control overseas. Therefore, Spinosad is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Zeta-cypermethrin

Mode of Action and Overview

Zeta-cypermethrin is classified as a Pyrethroid (MOA 3A). It is a non-systemic insecticide that is reported to provide 'excellent' control of SWD overseas (University of Connecticut 2018a; b). Zeta-cypermethrin is currently used overseas for the control of SWD as discussed below.

Overseas use patterns

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
Cane berries (raspberry, blackberry, etc)	United States (Special label for use in Alabama, Florida, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Virginia, West Virginia, Wisconsin and Washington only)	Hero (1.24 lb a.i/gallon (148.6 g a.i/L)) is used at 6.4-10.3 fl. oz./acre (467.7-752.7 ml (69.5-111.9 g a.i) applied in 50 gallons/acre (467.7L/ha) of water. The label says multiple applications are permitted at 7+ day intervals but not to apply more than 27.4 fl. oz/acre (2,002.3 ml (297.5 g a.i)/ha)/year.	No Australian labels or permits for this crop/insecticide combination	Not applicable
Blueberry	United States (Special label for use in Alabama, Florida,	Hero (1.24 lb a.i/gallon (148.6 g a.i/L)) is used at 6.4-	No Australian labels or permits for this	Not applicable

CROP	COUNTRY	RATE	AUSTRALIAN RATE	COMPARISON TO AUSTRALIAN USE PATTERN
	Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Virginia, West Virginia, Wisconsin and Washington only)	10.3 fl. oz./acre (467.7-752.7 ml (69.5-111.9 g a.i) applied in 20 gallons/acre (187.1L/ha) of water. The label says multiple applications are permitted at 7+ day intervals but not to apply more than 46.35 fl. oz/acre (3387.2 ml (503.3 g a.i)/ha)/year	crop/insecticide combination	
Grapes	United States (Special label for use in Alabama, Florida, Georgia, Maine, Maryland, Massachusetts, Michigan, New Jersey, New Carolina, Ohio, Oregon, Pennsylvania, Rhode Island, South Carolina, Virginia, West Virginia, Wisconsin and Washington only)	Hero (1.24 lb a.i/gallon (148.6 g a.i/L)) is used at 6.4-10.3 fl. oz./acre (467.7-752.7 ml (69.5-111.9 g a.i) applied in 25 gallons/acre (233.8L/ha) of water. The label says multiple applications are permitted at 7+ day intervals but not to apply more than 10.3 fl. oz/acre (752.7 ml (111.9 g a.i)/ha)/year.	No Australian labels or permits for this crop/insecticide combination	Not applicable

Efficacy against SWD

Zeta-cypermethrin is registered for use overseas suggesting that it has some efficacy against SWD.

The University of Connecticut (2018a; b) rate Zeta-cypermethrin as providing 'excellent' control of SWD on berries and stone fruit crops.

Impact on beneficial organisms

Biobest Side-Effects Manual (2019) does not list Zeta-cypermethrin but suggests that Cypermethrin is 'toxic' to most beneficial organisms listed in the manual. Similarly, Pyrethroids are listed as posing a 'very high' impact on beneficial insects on cotton (CRDC and Cottoninfo 2018).

Data requirements for permit applications

Zeta-cypermethrin is used overseas for SWD control on, rubus berries, blueberries, and grapes but is not used in Australia on those crops. This means that additional crop safety and residue data is likely to be required to support a future permit application based on the overseas use patterns.

Summary

Zeta-cypermethrin is used overseas under labels for the control of SWD but the pesticide is not used in Australia on the listed crops. Therefore, Zeta-cypermethrin is not considered suitable for on-going management of the pest without access to additional supporting data that would support the creation of an APVMA permit.

Recommendations for suitable pesticides for future SWD permits

Based on a comparison of the overseas use patterns for the control of SWD and the existing Australian use patterns it is recommended that the following pesticide:crop combinations should be considered for future permit applications:

1. Maldison on berries (including Strawberries, Rubus berries, Ribes berries, Blueberries), stone fruit (including apricots, cherries, nectarines, peaches and plums) and grapes.
2. Bifenthrin on Rubus berries, gooseberries and Blueberries.
3. Clothianidin on peaches should be considered.

These pesticides have been selected as the Australian and overseas use patterns are comparable meaning that permits should be easily applied for without the need for local residue and crop safety trials that may be needed for other pesticides that are used overseas for SWD control.

It is also recommended that further research is undertaken to determine suitable control options for SWD on citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), figs, kiwi, pome fruit (apples and pears), pomegranate and tropical/sub-tropical species (e.g. guava and feijoa). As no pesticide options were identified that are used in Australia on the listed crops at the same rate as they are used overseas for SWD control, making this a gap in Australia's preparedness for SWD.

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APPENDIX 1

Table 2 provides a summary of the effectiveness of the different actives for SWD control as well as providing information on the impact of the insecticide on beneficial organism and information on the data needed to support permit applications. A colour coding system has been developed where green are the best options (ie effective, low impact, limited additional data required), yellow are less preferred options followed by orange and then red as the least preferred options. This information can be used to determine the most suitable insecticide options to pursue for SWD control.

Table 2 Summary of effectiveness, impact and data requirements for identified insecticides

PRODUCT	EFFECTIVENESS (AS PER UNIVERSITY OF CONNECTICUT 2018 A AND B)	COMPARISON OF OVERSEAS AND AUSTRALIAN USE PATTERNS	DATA REQUIRED	IMPACT ON BENEFICIAL ORGANISMS (BASED ON BIOBEST SIDE-EFFECTS MANUAL (2019) AND CRDC AND COTTONINFO 2018)
Bifenthrin	Excellent	Used in Australia at higher rates than overseas (one or more crops)	No additional trial data needed	Toxic
Spinetoram	Good-excellent	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Non-toxic to slightly toxic (low cotton beneficial toxicity based on CRDC and Cottoninfo 2018)
Clothianidin	Good	Used in Australia at higher rates than overseas (one or more crops)	No additional trial data needed	Moderately toxic (based on CRDC and Cottoninfo 2018)
Cyantraniliprole	Good-excellent	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Moderately toxic (based on CRDC and Cottoninfo 2018)

PRODUCT	EFFECTIVENESS (AS PER UNIVERSITY OF CONNECTICUT 2018 A AND B)	COMPARISON OF OVERSEAS AND AUSTRALIAN USE PATTERNS	DATA REQUIRED	IMPACT ON BENEFICIAL ORGANISMS (BASED ON BIOBEST SIDE-EFFECTS MANUAL (2019) AND CRDC AND COTTONINFO 2018)
Maldison (syn. Malathion)	Good	Used in Australia at higher rates than overseas (one or more crops)	No additional trial data needed	Toxic
Spinosad	Good	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Non-toxic to slightly toxic (low cotton beneficial toxicity)
Methomyl	Excellent	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Toxic
Beta-cyfluthrin	Excellent	Not used in Australia on target crops	Safety and residue	Toxic
Cyclaniliprole	Good-excellent (approximation - not covered in University of Connecticut 2018 a or b)	Not used in Australia on target crops	Safety and residue	Toxic
Esfenvalerate	Excellent	Not used in Australia on target crops	Safety and residue	Toxic
Lambda cyhalothrin	Good-excellent	Not used in Australia on target crops	Safety and residue	Toxic

PRODUCT	EFFECTIVENESS (AS PER UNIVERSITY OF CONNECTICUT 2018 A AND B)	COMPARISON OF OVERSEAS AND AUSTRALIAN USE PATTERNS	DATA REQUIRED	IMPACT ON BENEFICIAL ORGANISMS (BASED ON BIOBEST SIDE-EFFECTS MANUAL (2019) AND CRDC AND COTTONINFO 2018)
Phosmet	Excellent	Not used in Australia on target crops	Safety and residue	Toxic
Zeta-cypermethrin	Excellent	Not used in Australia on target crops	Safety and residue	Toxic
Cyantraniliprole + Abamectin	Excellent	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Moderately toxic (based on CRDC and Cottoninfo 2018)
Diazinon	Good	Not used in Australia on target crops	Safety and residue	Toxic
Lambda cyhalothrin + Thiamethoxam	Good	Not used in Australia on target crops	Safety and residue	Toxic
Acetamiprid	Fair	Not used in Australia on target crops	Safety and residue	Moderately toxic - toxic
Fenpropathrin	Excellent	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Toxic

PRODUCT	EFFECTIVENESS (AS PER UNIVERSITY OF CONNECTICUT 2018 A AND B)	COMPARISON OF OVERSEAS AND AUSTRALIAN USE PATTERNS	DATA REQUIRED	IMPACT ON BENEFICIAL ORGANISMS (BASED ON BIOBEST SIDE-EFFECTS MANUAL (2019) AND CRDC AND COTTONINFO 2018)
Chromobacterium subtsugae Strain PRAA4-1 and spent fermentation media	Fair to poor	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Non-toxic (based on label)
Imidacloprid + Cyfluthrin	Good	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Toxic
Cypermethrin	Suppression (based on label. Not covered in University of Connecticut 2018 a or)	Not used in Australia on target crops	Safety and residue	Toxic
Burkholderia spp. Strain A396	Suppression	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Non-toxic (based on label)

IMPROVING THE BIOSECURITY PREPAREDNESS OF AUSTRALIAN HORTICULTURE FOR THE EXOTIC SPOTTED WING DROSOPHILA

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Contents

ACRONYMS AND DEFINITIONS

ACRONYM OR TERM	DEFINITION
ACV	Apple cider vinegar
EPPRD	Emergency Plant Pest Response Deed
HPI	Host Potential Index
HPP	High Priority Pest - A plant pest that has been identified to have one of the highest potential impacts to a particular plant industry and is listed in a Biosecurity Plan or in Schedule 13 of the Emergency Plant Pest Response Deed. An outcome of a prioritisation process.
ICA	Interstate Certification Assurance
NPPP	National Priority Plant Pest
Pest	Plant pest includes insects, mites, snails, nematodes and pathogens (diseases) that have the potential to adversely affect food, fibre, ornamental crops, bees and stored products, as well as environmental flora and fauna.
SWD	Spotted wing drosophila (*Drosophila suzukii*)

1 EXECUTIVE SUMARY

1.1 Purpose and background of this preparedness material

In the last decade spotted winged drosophila (SWD), *Drosophila suzukii*, has rapidly emerged as an agricultural pest of international importance. Accumulated international knowledge will be vital in developing effectiveness preparedness strategies for this pest for countries that have identified SWD as a major biosecurity threat, such as Australia.

The preparedness material provides background information on SWD to assist in determining the requirements for the initial response to a detection and management of this species in Australia. This report seeks to understand the impacts, the mechanisms for SWD to spread, and how potentially affected industries within Australia can best prepare for an incursion.

The information contained within this document is designed to:

1. Provide background information and actions to be considered to support preparedness activities for SWD.
2. Aid in decisions around feasibility of eradication or containment by providing information to be considered when developing a Response Plan to spotted wing drosophila. In Australia, any Response Plan developed using information in whole or in part from this preparedness plan must follow procedures as set out in PLANTPLAN (Plant Health Australia 2010) and be endorsed by the National Management Group prior to implementation.
3. Provide information that supports effective management of the pest that minimises the disruption to agricultural industries should eradication of an incursion be deemed not feasible.

Additional information can be found in the following supporting material[1]:

- Awareness material such as the fact sheets from Plant Health Australia (PHA), and commonwealth, state and territory jurisdictions.
    - http://www.planthealthaustralia.com.au/pests/spotted-winged-*Drosophila*/
    - https://www.dpi.nsw.gov.au/biosecurity/plant/insect-pests-and-plant-diseases/spottedwing-*Drosophila*

- Department of Agriculture, Fisheries and Forestry Biosecurity (2013) Final pest risk analysis report for *Drosophila suzukii*. CC BY 3.0. This document provides background information on spotted wing drosophila, and an analysis of projected entry, establishment, spread and economic impact of this pest for Australia.

A summary of each of the sections within this document is presented in the *Summary of information to assist in preparedness for SWD* section. This information has also been included in the Spotted Wing Drosophila Preparedness Basics document.

[1] Note that information gathered in this document includes literature searches and research and development that may supersede older supporting material

1.2 Summary of information to assist in preparedness for SWD

1.2.1 pest details

Spotted wing drosophila poses a serious threat to many Australian horticultural industries. In Australia it has been identified as a National Priority Plant Pest and a High Priority Pest of apples and pears, berries, blueberries, cherries, dried fruit, summerfruit, table grapes and wine grapes. SWD is an economically damaging pest because of its wide host range and, unlike most *Drosophila* species, females have the ability to infest ripening fruit before harvest. As a result, it is expected to have impacts on fruit quality and production and market access, requiring significant changes to management practices and movement controls.

Biology: *Drosophila suzukii* (Matsumura) is a member of the Diptera (fly) family. Like other flies, SWD is characterised by four distinct life stages. While immature life stages of most *Drosophila* are fungivores with some species being associated with yeasts in rotting fruits, SWD is markedly different in that it has a preference for egg-laying and larval feeding on ripening fruits. Unlike other *Drosophila* spp., female SWD can penetrate normally resistant fresh fruit skin using a serrated ovipositor to lay her eggs.

In laboratory trials, both summer and winter-adapted morphs have been shown to live up to 30–179 days, however, the life span of adults in the field is uncertain. After emergence, the adults typically become sexually mature in one to two days with a maximum of 13 days recorded. A female can oviposit 7–16 eggs per day with an average of 384 eggs laid during her life based on laboratory trials. More recent work has shown the average number of eggs laid per female over the first four weeks of oviposition ranges from 85 – 148 eggs. Host type as well as environmental factors, such as temperature, influences the number of eggs laid. Eggs, larvae and pupae all vary in development time depending on the environmental conditions, and generations over summer have the shortest development times. At 22°C, the egg stage takes 1.4 days, larval stage 6 days, pupal stage 6 days, making a total of 13–14 days to develop from egg to adult. This short development time allows the fly to complete several generations in a season.

It has been shown that sexually mature females enter reproductive diapause when the photoperiod is less than 14 hours at moderate temperatures (15 or 20°C), and at temperatures less than 10°C it will enter this diapause regardless of photoperiod.

Hatched larvae feed inside the fruit as they develop through three instars. When crop fruit is not available, wild and ornamental plants bearing fruit and dropped fruit or pomace have been found to sustain SWD. If the fruit has dropped to the ground, third instar larvae will move and pupate in the soil. On hanging fruit, larvae will often drop and pupate in the soil rather than remain in the fruit.

Hosts: While much of the focus on SWD is related to its status as a serious pest of soft and thin-skinned fruits, there is evidence that this pest has a potentially very wide host range. Various soft fruited crops including figs, stone fruit (apricots, cherries, nectarines, plums, peaches), strawberries, *Rubus* berries (raspberries, blackberries and related crops), *Ribes* berries (currents, gooseberries, etc.), blueberries, and grapes have been identified as hosts. Other thicker-skinned fruit such as citrus and pome fruit (apples and pears, kiwifruit, etc.) can also act as hosts when the fruit is damaged.

Research efforts have focussed on understanding the relevance of the various hosts of SWD, including whether the host is economically important, or whether the host provides potential breeding sites and may be important for establishment and spread. Further, while reports exist of host status under certain circumstances, in some cases this relates only to damaged fruit, or fruit infested under laboratory conditions. Such reports should not be automatically extrapolated to infer infestation under natural conditions.

In the event of an incursion, the wide host range, including many wild exotic and ornamentally cultivated plants, would still provide a significant habitat for this pest in Australia. Major hosts like blackberries are present and widespread within many environments as weeds, and the range of fruiting and ornamental plants in urban and peri urban plantings provides high likelihood for the establishment of SWD. The wide host range will also complicate local pest management, allowing populations to be supported outside of managed crops. The timing and extent to which SWD utilize non-crop resources is not well understood and will be likely to vary on a regional basis.

Signs and symptoms: SWD larvae cause damage by feeding on the pulp inside fruit and berries. Infested fruit show small scars and indented soft spots on the surface left by the ovipositing females. The infested fruit begins to collapse around the feeding site causing a depression or blemish on the fruit, and sap exudates may also be evident. The oviposition scar exposes the fruit to secondary attack by pathogens and other insects, which may cause rotting. If SWD attack is high, the entire fruit can collapse. Signs of infestation may be confused with normal ageing of mature fruit. However, fruit infested with SWD shows rapid softening and wrinkling within a few days after egg laying. Signs and symptoms of SWD may be delayed if fruit is cold stored, with symptoms of fruit collapse developing rapidly when fruit is brought out of cold storage.

Diagnostic considerations: Adult SWD are small flies 2–3 mm in length with a wingspan of 6–8 mm. They have prominent red eyes and are pale brown or yellow-brown in colour and have dark abdominal bands. The males are generally smaller than females and have a dark spot on the end of each wing. The females can be distinguished under a microscope from other *Drosophila* species by a double serrated ovipositor. The pupae are found in fruit and the soil, are 1 mm wide, 2–3 mm long and red to brown in colour. They are oval shaped and have a pair of distinctive horn shaped protrusions (respiratory organs), which divide into 7 or 8 branches at one end and a small v-shaped structure at the other (also for respiration). Larvae of SWD are cream to white maggots, approximately 3 mm in length. Eggs of SWD are white, oval shaped, 0.6 mm in length and have two filaments at one end for respiration.

Superficially SWD is very similar and can be easily confused with endemic insects, with several similar *Drosophila* species common in rotten fruit in Australia and, as a result, identification based on visual signs of the pest will be problematic. Diagnostic considerations for SWD include the following:

- The presence of spots on the wings of adult males is highly distinct and would not be observed in any other *Drosophila* species present within Australia or New Zealand.
- Distinctive morphology of the dark combs on the basal tarsal segments of adults. Male *D. melanogaster* and *D. simulans* are superficially similar to SWD in usually possessing dark tipped abdomens but they differ in the morphology of the combs on the basal tarsal segments and in having non-spotted wings.
- The well-developed and sclerotised ovipositor on adult females is also an important, though not entirely unique, characteristic that could be observed with hand lenses. Female *D. immigrans* are superficially similar in the morphology of the ovipositor, however in female SWD the ovipositor is strongly sclerotized with robust teeth along the lower half towards the ovipositor tip. The relative size of the ovipositor compared with the spermatheca also differs substantially between these two species.
- Immature stages (eggs, larvae, pupae) can only be differentiated from closely related *Drosophila* species in Australia, using molecular methods, or by rearing them into adults.

Geographic distribution: The native geographical range of SWD is thought to include ten countries in south-east Asia, ranging from Japan to Pakistan and was known to cause economic damage within some of these countries. SWD is rapidly becoming a global concern, having recently spread to North America, South America and Europe. Global attention was only drawn to its impact on fruit production and quality after its spread to these areas. The subsequent establishment of SWD within the United States and Europe has led to major impact to horticultural industries, especially blueberries, caneberries (i.e. *Rubus* species like blackberries, loganberries, and raspberries), cherries, summerfruit and table grapes. It is important to note that no country has eradicated SWD and it appears to spread very rapidly after initial detection.

1.2.2 Risk

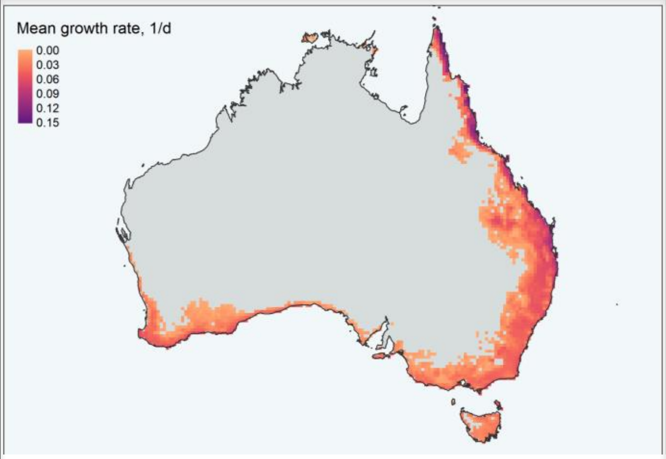
When the first detections around the world are viewed in aggregate, several commonalities can be seen that may help Australia consider pathways and possible sites of first arrival and detection. For a SWD incursion to occur via infested fresh fruit a number of steps must take place:

1. Infestation of fruit in the field
2. Survival of post-harvest processes
3. Survival during transport
4. Entry into new regions/countries
5. Development through to adulthood (for egg/larval/pupal life stages)
6. Exposure to a suitable feeding host
7. Locating a mate (unless a mated adult female enters)
8. Locating a suitable host for oviposition

Most of these steps are discussed in detail in the pathway risk analysis that the Ministry for Primary Industries has undertaken for SWD for fresh produce from the USA and the pest risk analysis that the then Australian Department of Agriculture, Fisheries and Forestry conducted for SWD (MPI 2012, DAFF 2013). These documents are a good basis for assessing the risk associated with the pest and the fresh produce pathway.

Overall it has been determined that the likely risk of transmission of SWD to Australia would be low due to: 1) current import and phytosanitary restrictions on exporters of high-risk commodities 2) small volumes of imported fresh fruit due to limited demand 3) requirements for declaration of any plant-derived goods associated with passenger movements and mail 4) the low likelihood of natural spread to Australia. However, to further minimise risk of establishment, it is necessary to prioritise surveillance activities, including how and where to undertake monitoring activities.

Independent studies modelling the potential global distribution of SWD have concluded that there are substantial regions of Australia with high climatic suitability (dos Santos et al. 2017, Ørsted and Ørsted 2019). Building upon these studies **cesar** have developed a model of establishment potential of SWD in Australia. The full report can be found at https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/. A large portion of Australia's southern and eastern coastal fringe, as well as some restricted areas in western Australia were predicted to have climates that will support SWD populations (see image right)



climates that will support SWD populations and predicted growth rates this is the mean population growth rate averaged across the year, indicating permanent populations are likely to establish (year round populations).

One of the most important attributes of SWD as a plant pest is its ability to invade a region quickly. This is largely due to high reproductive rates, relatively long life, broad host range, and capacity to survive in both cool and warm areas. **cesar** modelled the ecoclimatic and anthropogenic drivers of SWD establishment and spread to improve forecasts of incursion scenarios into Australia. Simulation results showed that despite variation in human population densities and climatic suitability between modelled incursion scenarios, in the absence of interstate quarantine measures, SWD was predicted to rapidly fill its climatic niche in Australia with only minor variation in likely spread pathways across 6-year incursion simulations. At shorter timescales, incursion location had a large impact on spread potential. Nevertheless, the high spread potential of SWD and low sensitivity of current surveillance methods will make post-incursion eradication programs challenging and costly, suggesting that border-security and quarantine procedures will constitute be crucial preventative measures.

When considering risk pathways, the following points are important to consider.

- International travel and movement of goods between countries pose the most significant risk of this pest being introduced into Australia.
- Regarding Australian imports of fresh plant products, the commodities posing most risk are the primary/preferred hosts like caneberries (blackberries, raspberries, loganberries, youngberries), blueberries, strawberries, grapes, summerfruit, cherries and currants. These commodities are most susceptible as hosts just prior to or at harvest. However, SWD has a very wide host range with other fruits often recorded as hosts when damaged or when beyond commercial maturity, for example, peaches, pome fruit, oranges, and even mushrooms.
- Some "secondary host/low host-risk" commodities are imported in much higher volumes than preferred-hosts and may thus still pose import risks for SWD. The volume at which they are imported into different state-level jurisdictions, coupled with previous regional analysis on establishment and spread risks, suggests surveillance efforts may increase the chances of early detection by prioritising monitoring in winter-spring periods around ports of entry for Victoria, New South Wales, and Queensland.
- Natural pathways of spread into Australia (e.g. through adult flight) are likely to be extremely low given Australia's natural geographic isolation and the low rates of natural spread observed overseas.
- Our landscapes are abundant in non-commercial hosts, such as wild blackberry and prickly pear, which could support SWD populations in persisting when commercial crops are not available.
- Based on modelling, SWD is predicted to rapidly fill its climatic niche in Australia. Models show only minor variation in likely spread pathways across 50 replicated 6-year incursion simulations. This highlights the rapid spread potential of SWD in Australia in the event of an incursion, and the importance of border-security and quarantine procedures.

Economic impact

Worldwide, the economic impacts of this pest for horticultural industries have been significant. The magnitude of economic damage associated with SWD can, in part, be attributed to the morphology of the female oviscape valve. Damage occurs through direct yield loss and reduced marketability of fruit with no practical option for treating infested commodities or redirecting them to alternative markets. Economic impacts from SWD include yield loss, management costs, post-harvest sorting costs, and potentially market access implications.

After compiling international reports of crop losses, most variation in impacts was associated with commodity type and years since establishment. The association with commodity type is likely to reflect intrinsic factors such as permeability of fruit skin or frost susceptibility, while the negative association with years since establishment likely reflects changes in cultural practices, such as harvest schedules, and chemical and biological control strategies in response to the new pest. This finding will help justify a quick transition to best practice management practices to avoid the initial high losses following establishment.

The economic impact potential of SWD to Australian horticulture has been predicted by a spatially explicit simulation framework by **cesar** (Maino et al. 2020a). The estimated unmitigated impacts of SWD in Australia were substantial, particularly for southern soft-fruit growing industries. Across simulated incursions in Adelaide, Devonport, Cairns and Mildura, there was little variation in accumulated impacts following 6 years after the incursion ($195 – 257 million) reflecting rapid spread into its suitable range. Unmitigated impacts were defined as the direct cost in terms of lost production associated with the predicted spread and establishment of SWD without mitigation (e.g. implementation of surveillance, quarantine, or management programs for SWD). In the model losses were estimated as a proportion of crop production value. Impacts that include loss of market access would further increase these losses as domestic movement of fruit is impacted as well as export markets where SWD is free

1.2.3 Considerations and recommendations for planning surveys

Because SWD has not been reported as a severe insect pest of fruit in its native region, no effective monitoring tools were available prior to its invasion of North America and Europe in the late 2000s. To date there have been two key detection methods in the incursion examples from around the world – trapping and reporting of crop damage following crop inspection. A range of traps (malaise, bottle and tephri traps) baited with a variety of attractants (beer, wine, fruit, apple cider vinegar or a combination) have resulted in first detections. Since those first detection, improved attractants continue to be developed.

Detection and delimiting surveys are required to determine the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established. Determining the most likely point of entry of SWD in Australia or New Zealand will be speculative as there are many inconsistencies with the first detections of SWD around the world. Information from overseas indicates that any level of trap capture may be indicative of a high population of SWD in the surrounding area (Kirkpatrick et al. 2017, Kirkpatrick et al. 2018a). The chance of trapping the first individuals is therefore considered to be low without a high density of traps.

Considering these limitations information provided in the following sections provides a framework for key points of consideration for development of early detection, delimiting surveys and surveillance for management for SWD.

When considering surveillance in Australia, climatic suitability, land use, host availability, season, points of entry, origin of fruit imports and fruit disposal should be taken into account. In summary surveillance priorities for detection and delimiting SWD should consider the following details:

- Larval extraction using flotation is a good indicator of actual threat to crops.
- Crops, wilderness areas and urban environments are all possible detection sites.
- Landscape level factors such as seasonal movement between hosts or at differing altitudes should be taken into consideration.
- The first trap captures in Europe generally occurred in July-October and built up over the season. The Southern hemisphere equivalent to this first trap capture period is January to March. SWD has been detected via trapping from August to March in the Southern hemisphere. However, detection year-round may be possible in parts of Australia that have a similar climate to that of the United Kingdom, where SWD is trapped throughout the year.
- Common trap-and-lure systems designed for SWD show inconsistent performance. This is problematic as ineffective trap-and-lure systems may fail to detect SWD populations early enough for control actions to be taken or may underestimate the extent of a SWD problem in the field.
- As the number of available attractants increases and their compositions evolve, there is a continued need to test trap type and attractant combinations ('trapping systems') in specific regions and crops so that growers can select optimal tools for monitoring programs.
- Often ripening fruits are more attractive than traps and lures, highlighting the need to capture flies after overwintering period before fruit is widely available in the landscape.
- Lower trap catches in crop due to competition with fruit and pesticide application compared to surrounding wild areas (Dr Bethan Shaw, pers. comm.).
- If SWD were to be found in production areas the surrounding landscape will play an important role in determining likely crop infestation dates, with recent overseas research drawing a link between proximity of woodland refuges and early infestation of fruit.

Considerations for early detection

The type of sites where SWD is likely to first arrive are difficult to determine, as overseas examples have shown the first site of detection is not necessarily the invasion epicentre. If broad trapping grid were to be established in Australia it is unlikely to be effective for early detection as even a large surveillance effort of 1 trap per hectare only provides ~50% confidence that the trap will detect densities of SWD of 100 individuals per hectare in one week. In addition, this broad (untargeted) trapping grid will be cost-prohibitive in Australia as it has been estimated a 1 trap/hectare grid across the current area of 70,000 hectares of horticultural production would cost $70 m per annum to implement.

Given this cost, there is a need to focus surveillance efforts to ensure they are cost effective, and the points below provide a set of factors that should be considered when determining likely sites to improve detection.

- The most important pathway into Australia will likely be through fruit that is imported and then sold to consumers. This indicates that urban areas are likely to be the environment where SWD populations will first occur.
- Areas where fruit are collected, stored or particularly where waste fruit are dumped should be a focus of surveillance.
- The location of high throughput ports or airports may be important to note, particularly those ports where fresh fruit is being imported from countries where SWD is present.
- The location of fruit distributors, wholesalers and retailers will be important to target, and in particular, disposal areas of unsold imported fruit from wholesalers or retailers may present a risk.

Considerations for delimiting surveillance

Delimiting an incursion of SWD will be difficult as trapping efficiency has shown to be very low (1% of population size) as a result of the lack of specificity in current trapping options. Despite these limitations, the following points provide a set of factors for consideration for delimiting surveillance.

- Surveillance to delimit an incursion of SWD should take into account tracing information as outlined in Section 5.1.1 to determine potential pathways for movement of material to or from the site of the initial detection.
- At each site, preferred host plants of SWD should be selected for surveillance. This includes wild hosts (refer to Section1.2).
- SWD is not a strong flier, but can be easily moved long distances in infested fruit.
- At low densities, SWD has a relatively low detectability. Figure 26 illustrates the number of traps per hectare required to detect SWD at various population densities.
- If suspicious damage is detected, fruit samples should be collected (see Section 5.13), and traps should be placed around the affected area, in an attempt to capture adults and diagnose the fly responsible for the damage.
- If SWD are confirmed, visual surveillance supported by trapping should be used to monitor around the site of detection
- Surveillance should be accompanied with awareness material, signs and personal visits to households and businesses within the surveillance zone and buffer zones.
- Detection year-round may be possible in parts of Australia. In winter months, trapping should occur within non-crop hosts.
- It is important to have traps deployed to capture adult SWD after the winter diapause.

Surveillance should involve a combination of the following:

The efficacy rates of traps and lures have been shown to be highly variable, with efficacy dependent on host crop, reproductive status of SWD and other physiological parameters and behavioral priorities that may impact attraction to baits/lures. Points for consideration for any type of surveillance include:

- Visual inspection of fruit is a useful method in high risk areas (e.g. edges of crops or orchards with mature fruit or vegetables).
- If trapping is used, it should comprise two forms of lures - one a yeast based lure, the other a wine/apple cider vinegar (ACV) based lure or a commercial lure based on fruit volatiles.
- Fruit sampling via flotation tests for larvae using sugar water is a useful tool as larval contamination is a good indicator of the actual threat to crops.

1.2.4 Potential response options following detection of SWD

Eradication

For the range of specifically designed procedures for the emergency response to a pest incursion (including a general communication strategy), refer to PLANTPLAN (Plant Health Australia 2019).

For eradication to be considered a range of factors will need to be considered, and an assessment of these factors has been conducted which take into account the technical feasibility of eradication criteria outlined in PLANTPLAN 2019 (Table 1). It is important to note that this table has been pre-emptively compiled and that there are no current incursion points of SWD. Information in Section 2 of the table is therefore inclusive of general information that is relevant to any detection point.

SWD is highly fecund, develops rapidly, and uses a large number of fruits from commercial to weed species as hosts. Eradication potential will likely be low and will require early detection during its invasion, with rapid host plant movement controls - effectively treating it like a Tephritid fruit fly. No country has eradicated SWD and it appears to spread very rapidly after initial detection. This is likely to be a result of several factors including:

- The apparent rapid spread between regions and countries could be an artefact of the response post detection. i.e. Following an initial detection, increased awareness and surveillance occurs which identifies and delimits populations that are already well established.
- The ability of SWD to spread long distances through human assisted movement is exacerbated by its cryptic nature (small eggs and larvae and its superficial similarity to other *Drosophila* species), meaning it could go undetected for a long period of time.
- SWD is highly fecund and has a wide host range, both in crops under commercial production as well as wild non-crop hosts.

It should also be noted that prior to the development of synthetic lures, the technical feasibility of eradication was hampered by the lack of suitable tools to detect SWD. While a range of synthetic lures are now available, they have been developed to assist management of the pest overseas, and their efficacy in supporting an eradication response is untested.

Potential tools for the destruction of SWD are outlined under Management options in this section. It should be noted that these options have been used overseas to manage and control SWD, and no single tool is likely to be effective for eliminating this pest.

Table 1: Summary of factors to be considered in determining whether eradication or alternative action will be taken for an incursion of SWD

TECHNICAL FEASIBILITY OF ERADICATION CRITERIA	FACTORS TO BE CONSIDERED	***SUPPORTS*** **OR IS AN** ***IMPEDIMENT*** **TO SUCCESSFUL ERADICATION OR IS** ***UNKNOWN***
1. Aspects of the species biology that influence the ability to eradicate SWD		
1.1. Ability of SWD to establish and spread	• There is evidence that this pest has a potentially very wide host range including widely distributed non-crop hosts. • The short development time of immature stages of SWD allows the fly to complete several generations in a season with up to 13 generations recorded in field conditions in Japan. • Adults can travel short distances by flying (up to 9 km per generation). Natural pathways of spread into Australia (e.g. through adult flight) are likely to be extremely low given Australia's natural geographic isolation and the low rates of	Impediment to successful eradication

	natural spread observed overseas. • Human mediated dispersal has been the main cause of long-distance dispersal within and between countries overseas. • No country has eradicated SWD and it appears to spread very rapidly after initial detection. • A cryptic appearance, a lifecycle that is partially protected within fruit, and the presence of morphologically similar species in Australia is likely to hinder early detections, meaning significant spread could have occurred by the time a first detection is made. • There are substantial regions of Australia with high climatic suitability and it is predicted that without any mitigation or management SWD will rapidly fill its climatic niche in Australia within 6 years, irrespective of its incursion point. To counter this point, movement restrictions on fruit and plants currently in place between jurisdictions on other pests such as Queensland and Mediterranean fruit flies, are likely to support containment or slow spread from an area of initial detection. • Peak periods of human movement (e.g. summer) may strongly influence rate of spread. Ability to check travelers for infested fruit at border points will be a factor in spread rate.	
1.2. Ability of SWD to persist in the environment	• SWD have the ability to overwinter and survive in both cool and warm areas. Some regions of Australia will support year-round reproduction, e.g. coastal tropical and sub-tropical eastern Australia. • When an actively growing commercial fruit host is not available, dropped fruit or pomace and wild and ornamental plants bearing fruit have been found to sustain SWD. • Where there are high daily temperature and humidity fluctuations, SWD can exploit micro-climates to survive e.g. SWD will move throughout the crop canopy during the day and can use exposed fruit as a refuge. • SWD undergoes reproductive diapause during temperature extremes in order to ensure oviposition occurs at times when local climatic conditions are most likely to support larval survival.	
2. The current circumstances of the incident that influence the ability to eradicate SWD[2]		
2.1. Suitability of current circumstances to establishment and spread	• Host are widely distributed within Australia therefore any post border incursion can potentially result in establishment and spread. • Trap capture rates suggest that any level of trap capture may be indicative of a high population of SWD in the surrounding area. • The ability to delimit spread using current trapping methods for SWD is limited due to low sensitivity of traps.	Impediment to successful eradication
2.2. Ability of quarantine and other measures to contain SWD	• Current import and phytosanitary restrictions on high-risk commodities for SWD (as identified in the pest risk analysis) are in place. • Both government jurisdictions and industry peak bodies have the capability of putting in place awareness campaigns for industry and the general public to support containment measures.	Supports successful eradication

[2] Note that this information has been compiled pre-emptively and there are no current detections of SWD.

	• Interstate Certification Assurances (ICAs) that manage and mitigate the movement of Queensland fruit fly and Mediterranean fruit fly within Australia may be employed to restrict movement of SWD.	
3. The ability to accurately diagnose SWD	• An EPPO diagnostic protocol for spotted wing drosophila (EPPO 2013) is available and should be referred to for the diagnosis of suspected SWD. Further to this, a draft diagnostic identification protocol has been produced for Australia (Blacket et al. 2015), and diagnostic information is also available on Fruit Fly ID Australia https://fruitflyidentification.org.au/species/*Drosophila-suzukii*/#gallery • Superficially SWD is very similar and can be easily confused with endemic insects, with several similar Drosophila species common in rotten fruit in Australia., as a result, identification based on visual signs of the pest will be problematic. • Lure / trap systems are available to enable collection of adults for diagnostics (but noting traps are not specific and will have levels of bi-catch). • Availability of adult morphological keys mean that taxonomic identification of adults is possible if skilled taxonomists are employed within state departments. • Larvae are easy to collect for diagnostics of SWD however immature stages (eggs, larvae, pupae) can only be differentiated from closely related Drosophila species in Australia, using molecular methods, or by rearing them into adults.	Current impediment to successful eradication
4. The ability to find all sites in which SWD may be present	• Recent modelling work predicts where regions of high establishment potential are located. • Micro-habitats can enable SWD survival outside of its optimal climatic range. • The sensitivity of surveillance for SWD is low. • Adult flies are likely to be more strongly attracted to ripening fruit than the currently available lures, and any detections in traps could therefore indicate a potentially large population SWD. • SWD has a wide host range including wild species, this includes wild blackberries which have wide distribution thus limiting the chance of finding all sites infected. • There is limited capacity to correlate trap captures or larval presence with the surrounding population density. • SWD may be suspected based on fruit symptoms, however as SWD larvae closely resemble other Drosophilidae and many Drosophila species have larvae that are commonly found in rotting fruit, definitive identification of SWD requires microscopic examination of well-preserved adult specimens. • With a wide host range and potential establishment in urban areas it may be that not all affected areas may be accessible due to the likelihood of establishment on private residences. • The most likely pathway into Australia will likely be through fruit that is imported and then on sold to consumers. This indicates that urban areas are likely to be the environment where SWD populations will first occur. • Strong communication networks and relationships in urban areas will be necessary to aid effective surveillance in these areas. • It is possible that given its similarity to other Drosophila spp, detection of SWD may occur some-time after the initial incursion, thus limiting the ability to conduct trace-back and trace-forward investigations.	Impediment to successful eradication

	• The stockpile of SWD lures in Australia, or the speed at which lures/traps can be made and deployed will influence how quickly populations may be detected, and control tactics executed.	
5. The presence of an effective control method that will remove or destroy all SWD present		
5.1. An effective control method is available/accessible	• No single treatment will be effective in eradicating populations of SWD and a combination of chemical treatments, cultural treatments and hygiene to remove and destroy fruit, will be required. • Eradication of SWD in urban and peri-urban environments will be difficult as either a combination of chemical or cultural treatment or removal of all hosts would be required. Follow up surveillance and treatment to remove all stages of the SWD life cycle will be needed • Chemical treatments only target adult flies, there are no chemical control methods for the immature stages of SWD. • There is recent evidence of emerging resistance to one chemical frequently used for SWD management.	Impediment to successful eradication
5.2. Control method can be implemented to remove SWD at a faster rate than it can propagate/spread	• The rapid reproduction rate of SWD and the lack of a chemical control methods that targets all life stages may result in the spread and reproduction that is faster than the rate of control. • The wide host range including widely distributed weed host provide refuge areas in the surrounding landscape. • Rate of spread is influenced by transmission pathways and also climate, therefore seasonality will play a role. • Interactive incursion spread model developed by **cesar** can be used to identify possible rate of spread based on incursion point. https://cesaraustralia.shinyapps.io/SWDportal/	Impediment to successful eradication
5.3. Whether there are control methods commonly employed for endemic pests and diseases, that may limit the establishment, spread and/or impact of the EPP	• Movement controls and that manage and mitigate the movement of Queensland fruit fly (Qfly) and Mediterranean fruit fly (Medfly) (and other plant pests) within Australia may restrict movement of SWD. • In Australia, training and use of accredited market access assurance officers by farm businesses, or alignment with industry programs such as Biosecure-HACCP is an option for assisting support movement controls. • There are currently chemicals for the use of similar pests, however application would need to target adult SWD to be effective in reducing population density. • Most farms that manage Qfly are practiced in basing spray decisions on surveillance grid data. • Frequent harvest intervals for host commodities means there are regular opportunities for visual inspection and detection by orchard and packhouse staff. • In Australia the presence of Qfly and Medfly in different regions increases the likelihood of detection of infested fruit. i.e. in regions infested Qfly and Medfly, industry is constantly undertaking control and inspection procedures, and in regions considered free of these pests, producers are likely to notify if fruit is found to be infected with larvae.	Supports successful eradication
6. The likelihood of repeated introductions	• Strict movement controls and treatments are currently in place for SWD from countries/regions known to have established populations.	Supports successful eradication

* Note there is no current detection points for consideration information presented relates to any incursion point

Quarantine and movement controls

The analysis of the quarantine risks associated with SWD by Biosecurity Australia, 2013, identified several traded commodity groups that could serve as a potential pathway for SWD into Australia. This information has been built upon further to include pome fruit and citrus and mushrooms (see section 3.1.1). This work indicates that previously overlooked commodities with low host-preference are imported in such high volumes that they may pose import risks for SWD. To mitigate potential risks associated with fruit movement, an Interstate Certification Assurance (ICA) for irradiation treatment (ICA-55) has been identified as a potential fruit treatment for SWD. If Restricted or Quarantine Areas are practical, no fruit should be moved from the infested to non-infested areas without first being inspected and appropriately treated. Voluntary movement control should also be considered for urban/residential detections. Voluntary compliance is likely to be implemented for urban areas using awareness campaigns to highlight high risk goods/situations and appropriate treatments.

Management options

Effective management of SWD is a challenge owing to its wide host range and short generation time. Overseas SWD can only be managed using a systems approach using both chemical and non-chemical control Within Australia, the wide climatic zones spanned by berry, cherry, grape, and summerfruit growing regions will require unique management recommendations. Effective management of SWD overseas relies on various management strategies. Crop hygiene is considered to be of most importance and value, especially when coupled with cultural control practices such as microhabitat manipulation which has been shown to be an effective management tool for SWD. Many cropping systems have moved away from the use of chemicals as these have significant impacts on Integrated pest management (IPM) systems. A summary of current SWD management approaches overseas include:

1. Making production sites less favourable for SWD. This can be achieved through
    - Hygiene - removal of fallen or damaged fruit)
    - Cultivar selection – selection of early maturing varieties
    - Weed fabric – to limit refuge sites for adults and ability for pupae to enter soil
    - Pruning – for canopy management to limit refuge sites and to allow all fruit to be picked
    - Exclusion netting – to limit ability for adults to attack crops
2. Monitoring SWD flies in spring to detect first activity
3. Sampling fruit for larvae as it begins to ripen to determine population levels
4. Protecting ripening and ripe susceptible fruit. This can be achieved by
    - Weekly pesticide applications
    - Ensuring good coverage of sprays
    - Reapplication of pesticide after rain
    - Rotation of chemical classes
    - Consideration of both adult and larval control options
5. Post-harvest methods

Chemical control options

Chemical options would be made available to Australian growers if the pest were to be detected through the minor use and emergency permit system (and possible through registrations). However, chemical applications do have limits on how useful they are when it comes to spotted wing drosophila control. Many insecticide sprays target only the adult flies. Eggs and larvae are difficult to control because they are inside the fruit. Many of the chemical products are non specific and can disrupt beneficials and IPM systems. It is also important to consider that limited chemical options and regular chemical application may lead to increased risk of chemical resistance. Generally, before pesticides are legally allowed to be used in Australia labels or permits need to exist allowing the proposed use pattern. The most straightforward applications for emergency use permits are those where an overseas label specifies a pesticide:crop:rate combination (i.e. use pattern) that is the same as, or less than, the existing Australian use patterns. If the proposed use pattern is very different than local crop safety and residue trials may need to be established to collect data to support the proposed use pattern.

The following recommendations for chemical registrations have been made based on a comparison of overseas and Australian use patterns

1. Consider developing an APVMA permit for Maldison on berries (including strawberries, rubus berries, ribes berries, blueberries), stone fruit (including apricots, cherries, nectarines, peaches and plums) and grapes.
1. Consider developing an APVMA permit for bifenthrin on rubus berries, gooseberries and blueberries.
2. Consider developing an APVMA permit for clothianidin on peaches.

It is also recommended that further research is undertaken to determine suitable control options for SWD on citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), figs, kiwifruit, pome fruit (apples and pears), pomegranate and tropical/sub-tropical species (e.g. guava and feijoa). As no pesticide options were identified that are used in Australia on these crops at the same rate as they are used overseas for SWD control, making this a potential gap in Australia's preparedness for SWD. It should be noted that many of the recommended actives are non-selective and can interrupt IPM systems. Further research into "softer" chemistries for SWD control in Australia is required to fit into existing crop management practices.

Note, the high spread potential of SWD will make post-incursion eradication programs extremely difficult and expensive.

1.3 Recommendation for preparedness activities

If international experience with SWD is indicative of the risks posed to Australia's horticultural industry, considerable challenges lay ahead to minimise incursions, establishment, and spread, and ensure producers possess the knowledge to quickly and smoothly transition to management. Simultaneously, Australia is in the fortunate position to be able to utilise the rapidly accumulating scientific knowledge around this pest that would have been unavailable prior to 2008. If Australia utilises overseas experiences, through well-designed quarantine, diagnostics, surveillance and management strategies, the impacts of SWD can certainly be mitigated to a large degree.

1.3.1 Gaps in preparedness

Despite a growing volume of literature and knowledge on SWD there are knowledge gaps are outlined in Table 2 required to maintain or improve preparedness in Australia.

Table 2: Gaps in preparedness identified

GAPS IN PREPAREDNESS

Surveillance
 	
The following will need to be resolved/put in place to support surveillance for SWD
 	
▪ There are currently limited sensitive (selective) trapping techniques which would support biosecurity responses and ongoing monitoring effort
▪ There is currently no national or industry program of surveillance and monitoring of SWD
▪ There is a need to improve our ability to
    - Predict survival of overwintering populations that will emerge in spring
    - Understand the timing and extent to which SWD utilize non-crop resources on a regional basis

Information on control techniques There is limited information on the following areas: ▪ The effectiveness of mass trapping as a management tool to mitigate impacts of SWD in fruit production systems ▪ The effectiveness of lure and kill technology for management of SWD ▪ The effect of the current chemical and irradiation treatments used for the control of Tephritid fruit flies to control SWD ▪ Decision-aids to measure abundance and estimate crop impact in Australian regions There is a need to have the following in place to support management of SWD should it enter Australia: ▪ Identification of pest management techniques that are less disruptive to IPM practices than pesticide applications ▪ Continued collaboration with international relationships (i.e. sending researchers/growers overseas collect advice and find answers) ▪ Understand control costs at the farm and supply chain business scale ▪ Improve understanding of possible international trade-risk, as well as pre-emptive development of strategies to protect market access ▪ Agreed standard operating procedures for movement of produce from affected regions for Australian growers
Engagement and awareness The following will need to be put in place to support management of SWD should it enter Australia ▪ Communication and extension activities focused on urban or peri-urban environments

- Evaluation of farm-level metrics that will assist communication with industry to demonstrate how SWD management will impact cost-of-production
- Guidelines for a Communication Plan for communication and engagement with consumers and soft-fruit industries during response to an incursion

Diagnostics

The following will need to be finalised to support detection of SWD should it enter Australia

- Finalisation of the National Diagnostic Protocol for SWD
- Diagnostic tools that support high throughput diagnosis of SWD

1.3.2 Actions for future SWD preparedness

Based on overseas experience, responding to an incursion of SWD will be a challenging. SWD is highly fecund, develops rapidly, and uses a large number of fruits from commercial to weed species as hosts. Eradication potential will likely be low and to be successful will require early detection, with rapid implementation of host plant movement controls. Even where eradication of an incursion is deemed not technically feasible, early detection will still be vital to have the best chance of containment and to allow industries to rapidly implement management practices.

To continue to increase Australia's preparedness for SWD, further actions are required to fill gaps that have been identified (see Table 3). The action table sets priorities and proposed activity length required for the activity.

Table 3: Action areas required to fill gaps identified in preparedness for SWD

ACTION AREAS	PRIORITY	ACTIVITY LENGTH[3]
Prevention		
Maintain appropriate regulation at the border. Specifically: - Industry should engage with the federal government to ensure maintenance of appropriate conditions for limiting risk of long-range SWD transmission into Australia. - Governments should make use of pathway risk analysis conducted as a part of this project to improve risk mitigation where necessary.	High	Long
Ongoing collection and assessment of interception data by the federal government to identify any changes to the risk status of pathways	High	Long
Diagnostics		
Finalise the National Diagnostic Protocol for SWD	High	Short
Continue to develop high through-put diagnostic tools for rapid diagnostics and improvements to surge capacity[4]	Medium	Medium
Surveillance		
Provide key high-value host crop production regions with training and resources necessary to establish a program of surveillance for adults and larvae using traps and the flotation test	High	Medium
Establish a surveillance program in high risk sites such as fresh produce markets and areas that receive host products from overseas	High	Medium
Initiate regular reviews of new information on trapping and surveillance techniques used overseas to improve outcomes for early detection	Medium	Long

[3] Short term – up to 1-2 years; Medium term – 3-5 years; Long term 5+ years
[4] Noting that research is currently being undertaken in this area within the RRD4P project to improve diagnostics for plant pests in Australia

Develop and/or utilise tools and systems to capture, store and analyse surveillance, spatial and diagnostic data	Medium	Medium
Preparedness for management and control		
Review new information on lure and kill technologies as they it is developed overseas, including assessment of any barriers for registration for ongoing use of products in Australia	High	Short
Investigation into post-harvest treatments that may be applied to SWD-infested produce in Australia, with a view to understanding where treatments may align with Qfly arrangements, and where further data is necessary to support implementation of SWD arrangements.	High	Short
Application and ongoing review and maintenance of emergency permits for SWD. Specific requirements are: - An APVMA permit for Maldison on berries (including strawberries, rubus berries, ribes berries, blueberries), stone fruit (including apricots, cherries, nectarines, peaches and plums) and grapes. - An APVMA permit for bifenthrin on rubus berries, gooseberries and blueberries. - An APVMA permit for clothianidin on peaches.	High	Short
Where needed, undertake collation of appropriate efficacy data required for ongoing permits to support management, and provision of advice to permit holders in regard to necessary field trials for filling data gaps.	High	Medium
Undertake cost analysis for supply chain component to estimate additional expenses for management of SWD.	High	Short
Detailed investigation into alignment of Qfly management and SWD management in order to highlight where areas of similarity may support time and cost-savings.	High	Short
Undertake a short review of current export country partner requirements in relation to SWD, identify potential export risks and design of strategies for protection of market access, including development of standard operating procedures for movement of produce from affected regions for Australian growers.	High	Short
Ongoing research on control methods used overseas to continue to collect and refine management advice within an Australian context to mitigate the impacts of SWD in fruit production systems in the case of an incursion and establishment.	Medium	Long
Assess the effectiveness of hot and cold composting of fruit and waste for destruction of SWD, and waste burial tactics.	Medium	Medium
Investigate potential for deployment of Sterile Insect Technology in Australia, including compiling information on mass rearing techniques and undertaking a benefit:cost assessment for its use.	Medium	Short
Engagement and awareness		

Initiate an education campaign that promotes incorporation of cultural control management techniques, particularly related to hygiene and waste disposal, into best practice for fruit production for soft and thin-skinned fruits such as raspberry, blackberry, strawberry, blueberry cherry and summerfruit crops	High	Long
Maintain SWD engagement and awareness activities in raspberry, blackberry, strawberry, blueberry, cherry, tablegrape, and summerfruit industries. Expand awareness activities to pome and winegrape industries through strategic cross-industry and trans-Tasman collaborations.	High	Long
Investigate methods of strengthening communications between federal government biosecurity personnel and industry in order to support focussed awareness activities during high risk years	High	Long
Development of a communication plan for soft-fruit industries to support incursion response and business continuity in the event of an incursion, including: - Design of a public relations strategy to limit consumer backlash and support ongoing soft-fruit sales; - Clear messaging for farm and other supply chain businesses; - Methods of sharing information with affected and unaffected communities; - Identification of trusted advisors who could aid in communications.	High	Short
Design and implement an awareness campaign directed at urban and peri-urban communities surrounding high traffic ports-of-entry.	Medium	Short

2 PEST DETAILS

2.1 Biology

Common name	Spotted wing drosophila
Scientific name	*Drosophila suzukii* (Matsumura, 1931)
Synonyms:	*Leucophenga suzukii* (Matsumura, 1931)
Taxonomic position	Class: Insecta Order: Diptera Family: Drosophilidae Genus: *Drosophila* Sub genus: *Sophophora*

Drosophila suzukii (Matsumura) is a member of the Diptera (fly) family, where the adult stages are characterised by having one set of wings that are in front of a set of highly modified, vestigial wings called halteres. The family Drosophilidae is composed of over 3,750 species worldwide and over 2,000 of these are species of *Drosophila* (Ashburner and Bergman 2005, van der Linde and Houle 2008, O'Grady and Markow 2009). SWD belongs to the *Sophophora* subgenus of *Drosophila*, a group that contains a large number of species (>300 worldwide), including the common cosmopolitan *D. melanogaster* and *D. simulans* (O'Grady and Kidwell 2002). In Australia there are approximately 22 species from the *Sophophora* sub genus group present (Atlas of Living Australia, http://www.ala.org.au/).

Like other flies, SWD is characterised by four distinct life stages. The eggs are small (average 0.62 mm long, 0.18 mm wide) with two hair like respiratory tubes near the apex. While common to *Drosophila* species, these characteristics are distinct from the true fruit flies, members of the family Tephritidae. The larval (maggot) stages are also similar to other *Drosophila* species, including three distinct developmental stages (instars) that range from 0.67 mm x 0.17 mm to 3.94 mm x 0.8 mm in size. Larvae are white or cream in colour, being superficially similar to true fruit flies, though smaller in size. The pupal stage, where the larvae undergoes complete metamorphosis into the adult form, is approximately 3 mm long and 1 mm wide and tan to brown in colour. The pupal case has two respiratory tubes on one end, with each tube terminating in seven to eight branches. These respiratory tubes again distinguish *Drosophila* species from true fruit flies. The adult is 2.25 mm to 4.0 mm long with a wingspan of 6-8 mm, making any inspection difficult, unless magnification is used. The adult form is a small yellowish-brown coloured fly with distinctive red to orange coloured eyes. The abdomen has distinctive dark bands. Superficially this is the same as other *Drosophila* species that are commonly observed in urban and agricultural environments.

While immature life stages of most members of the family Drosophilae are fungivores with some species being associated with yeasts in rotting fruits (Colless and McAlpine 1991), SWD is different in that it can lay eggs in both ripening as well as overripe or damaged fruit. Unlike other Drosophilae, female SWD can penetrate the normally Drosophilid-resistant fruit epidermis to deposit her eggs.

SWD has two distinct morphs – a winter morph (cold adapted) and a summer morph (heat adapted). These morphs have different pigmentation, with the winter morph showing sporadic appearance of wing spots. Preliminary research from the United States suggests that winter morphs can 'smell' different volatiles to the summer morph. This means that each morph may be seasonally adapted to finding different hosts in cold and warm weather, further increasing its chance of persisting between cropping periods.

2.1.1 Lifecycle

The life span of adults in the field is uncertain. Both summer and winter-adapted morphs have been shown to live up to 30–179 d in the lab when provided food at various temperatures (Shearer et al. 2016, Rendon et al. 2020) and up to 10 weeks in small field cages during winter (Stockton et al. 2019). After emergence (pre-ovipositional), the adults typically become sexually mature in one to two days with a maximum of 13 days recorded (Kanzawa 1935, 1939) or 1–5 d old under standard lab conditions (Hamby et al 2016).

A female may lay 20–419 eggs under the skin of ripening and ripe fruit in a lifetime depending on conditions (Hamby et al. 2016). A female can oviposit 7–16 eggs per day with, an average of 384 eggs during her life in laboratory trials (Kanzawa 1939, Hamby et al. 2016). Eggs, larvae and pupae all vary in development time depending on the environmental conditions, with generations over summer having the shortest development times. At 22°C, the egg stage takes 1.4 d, larval stage 6 d, pupal stage 6 d, and a total of 13–14 d to develop from egg to adult (Emiljanowicz et al. 2014, Tochen et al. 2014). The short development time allows the fly to complete several generations in a season with up to 13 generations recorded in field conditions in Japan (Kanzawa 1939). The lifecycle of SWD at 22°C is presented in Figure 1.

It has been shown that sexually mature females enter reproductive diapause when the photoperiod is less than 14 hours at moderate temperatures (15 or 20 °C), and at temperatures less than 10 °C it will enter this diapause regardless of photoperiod. This is an adaptation which ensures that eggs can be held over during leaner times and are laid at times when larvae stand the best chance of thriving.

Hatched larvae feed inside the fruit as they develop through three instars. When crop fruit is not available, wild and ornamental plants bearing fruit (Lee et al. 2015, Kenis et al. 2016) and dropped fruit or pomace have been found to sustain SWD (Bal et al. 2017). If the fruit has dropped to the ground, third instar larvae will move and pupate in the soil (Ballman et al. 2017, Hübner et al. 2017). On hanging fruit, larvae will often drop and pupate in the soil rather than remain in the fruit (Woltz and Lee 2017).

Size of pest not to scale.

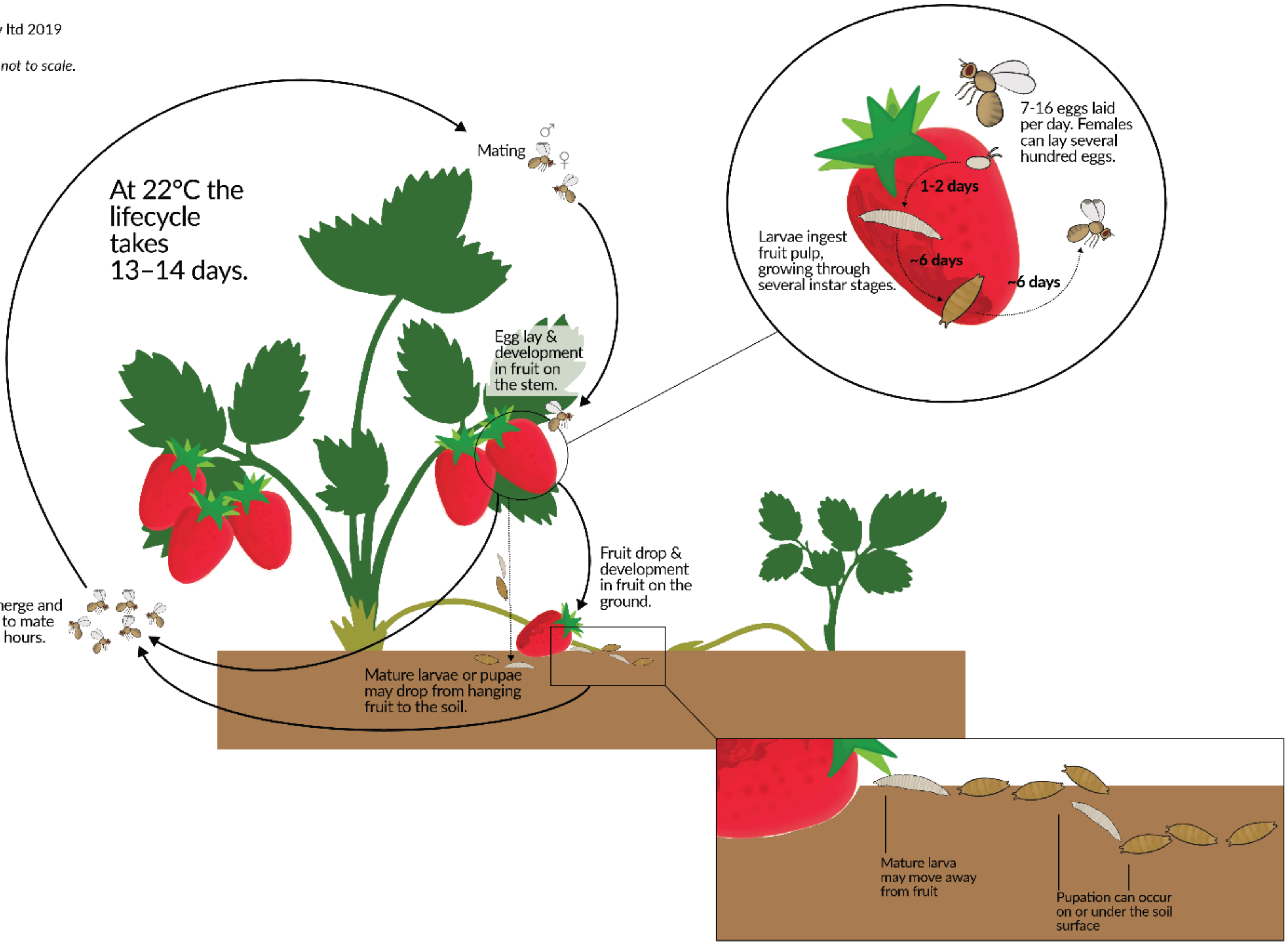


Figure 1: SWD lifecycle and development timeframes at 22 ℃

2.1.2 Dispersal

Despite its global significance, long range dispersal patterns of SWD after its arrival to new continents have remained largely unexplored. This limits our ability to predict how it will behave in other exotic ranges and thus limits capacity to develop preparedness strategies. It is known however that adults can travel short distances by flying (up to 9 km per generation) (Tait et al. 2018). Long distance movements within and between countries occurs through human-assisted dispersal (Adrion et al. 2014).

2.2 Hosts

While much of the focus on SWD is related to its status as a serious pest of soft and thin-skinned fruits, evidence gathered indicates that this pest has a potentially very wide host range. Various soft fruited crops including figs, stone fruit (apricots, cherries, nectarines, plums, peaches), strawberries, Rubus berries (raspberries, blackberries and related crops), Ribes berries (currents, gooseberries, etc.), blueberries, grapes and pome fruit (apples and pears, etc.) have been identified as hosts.

In the event of an incursion the wide host range, including many wild and ornamentally cultivated plants, would likely provide significant habitat and nutrition sources for this pest. The wide host range will also complicate local pest management, providing population sources outside of managed crops. While major hosts like blackberries are present and widespread within many environments, the assortment of fruiting and ornamental plants in urban environments and landscape plantings presents a potentially concerning situation for establishment of SWD. Nearby alternative hosts may serve as a refuge for pest survival and continued reproduction while crop fields are sprayed with insecticides to protect fruit from SWD. On the other hand, the presence of alternative hosts may also have benefits as shown in other pest–crop systems (Lee et al. 2015). A non-treated refuge could potentially delay the development of insecticide resistance, and can serve as a refuge for natural enemy populations that may be impacted in treated fields.

2.2.1 Host potential

While the SWD ovipositor allows for oviposition in fresh fruit hosts, not all hosts are equivalent in terms of suitability and potential for supporting egg viability and larval development. Differing physical properties of fruit hosts' surfaces likely influence oviposition and, consequently, oviposition preferences to varying degrees. SWD oviposition preference varies significantly between fruit hosts (Bellamy et al. 2013), and has been correlated with ripeness, pH, total soluble solids or Brix, skin penetration force, firmness of flesh, and indumenta (fuzz) (Lee et al. 2011a, Burrack et al. 2013, Hampton et al. 2014, Loriatti et al. 2015, Lee et al. 2015, Little et al. 2017).

A novel methodology for indexing the relative potential of crop hosts to function as resources (Host Potential Index – HPI) was developed as a practical framework to express relative host potential based on combining results from one or more independent studies, such as those examining host selection, utilization, and physiological development of the organism resourcing the host (Bellamy et al. 2013). The results from the interactions of SWD with seven ''reported'' hosts (blackberries, blueberries, sweet cherries, table grapes, peaches, raspberries, and strawberries) in a postharvest scenario were analysed using the HPI. Application of HPI methodology indicated that raspberries (HPI = 301.9 ± 8.39; rank 1 of 7) had the greatest potential to serve as a postharvest host for SWD relative to the other fruit hosts, with grapes (HPI = 232.4 ± 3.21; rank 7 of 7) having the least potential (Bellamy et al. 2013). This HPI is a useful tool for evaluating the risk of a host harbouring SWD populations, as well as identifying those crops (and cropping regions) that may be at greatest risk. However, more research is required in order to confidently identify the key factors that influence host preference and host potential.

Many studies have examined host suitability under laboratory conditions where the larval substrate is varied in development experiments, with the understanding that larval host nutritional quality impacts SWD development (generation) time and survivorship (Lee et al. 2011a, Bellamy et al. 2013, Burrack et al. 2013, Hardin et al. 2015, Jaramillo et al. 2015, Aly 2018). Under controlled conditions, SWD development time varies significantly based on fruit host.

2.2.2 Host preference

Laboratory tests have shown that SWD tends to perform better on commercially grown hosts rather than non-crop and ornamental hosts under similar trial conditions (Lee et al. 2011a, Lee et al. 2015) i.e. its strong preference is for commercial hosts. Among the commercial hosts that have been evaluated in the laboratory, such as cherries, blackberries, raspberries, and strawberries, SWD demonstrates highest egg lay and viability on raspberries (Lee et al. 2011a, Bellamy et al. 2013, Burrack et al. 2013, Tochen et al. 2014), aligning with observations in commercial settings where raspberries are infested at a greater rate than blackberries in the field (Burrack et al. 2013).

Further complications in understanding host dynamics is the lack of knowledge of the use of non commercial crop hosts. The timing and extent to which SWD utilize non commercial crop resources is not well understood and likely varies on a regional basis. SWD can potentially exploit locally-available springtime fruiting non-commercial crop hosts in temperate regions to increase adult population levels that later infest summer-fruiting commercial hosts. SWD may continue to infest available non-commercial host crops at the end of the growing season before going into reproductive diapause (Elsensohn and Loeb 2018).

2.2.3 SWD host list

The very wide host range of SWD can be divided into several host categories (see Table 4 for detailed description).

- Primary hosts – preferred hosts and able to support the full life cycle of SWD
- Secondary hosts – not preferred but can support development of SWD
- Wild non-crop (alternative) hosts – plants not grown for commercial production

Efforts have been focussed on understanding the relevance of the various hosts of SWD, including whether the host is important from the perspective of economic impacts, or whether the host is a potential breeding host and may be important for the pest's establishment and spread. Further, while reports exist of host status under certain circumstances, in some cases this relates only to already damaged fruit, or from fruit infested under laboratory conditions. Such reports should not be automatically extrapolated to infer infestation under natural conditions. Hosts in this report have been further defined by the reported host circumstances or conditions, such as

- Fallen fruit
- Damaged fruit
- Laboratory reared only
- Field collected
- Or a combination of reported conditions

A full host list is presented in **Appendix 1**. A summary of field collected primary, secondary and wild non-crop hosts is presented in Table 4.

Table 4: Host range of spotted wing drosophila divided into several host categories. All hosts listed have records of SWD being collected from fruit "in-field"

HOST CATEGORY	DESCRIPTION	SPECIES	
Primary hosts – field collected from otherwise undamaged fruit	These hosts are considered to be the most important for SWD based on infestation rates and commercial impacts, though it is noted that not all of the listed hosts are grown on large scales.	*Elaeagnus multiflora* (silver berry) *Vaccinium angustifolium* (blueberry) *Vaccinium corymbosum* (blueberry) *Vaccinium myrtilloides* (sourtop blueberry) *Morella rubra* (Chinese bayberry) *Fragaria ananassa* (strawberry) *Prunus armeniaca* (apricot) *Prunus armeniaca x salicina* (plumcot) *Prunus buergeriana* (shirozakura) *Prunus cerasus* (sour cherry) *Prunus domestica* (plum) *Prunus donarium* (wild cherry) *Prunus japonica* (Korean cherry) *Prunus mume* (Asian plum, Japanese apricot) *Prunus persica* (peach) *Prunus persica va. Nucipersica* (nectarine) *Prunus salicina* (Japanese plum) *Prunus sargentii* (Sargents cherry) *Prunus serrulata* (Japanese mountain cherry) *Prunus virginiana* (choke cherry) *Prunus yedoensis* (Tokyo cherry) *Prunus cerasus* (dwarf cherry)	*Rubus allegheniensis* (Allegheny blackberry) *Rubus armeniacus* (Himalayan blackberry) *Rubus idaeus* (raspberry) *Rubus laciniatus* (evergreen blackberry) *Rubus loganobaccus* (boysenberry) *Rubus parvifolius* (Japanese raspberry) *Rubus x loganobaccus* (loganberry) *Vitis labrusca* (concord grapes) *Vitis vinifera* (table grapes, wine grapes) *Aucuba japonica (Japanese aucuba)* *Vaccinium vitis-idea (Lingonberry)* *Maclura pomifera (Osage orange)* *Morus alba (White mulberry)* *Morus alba x rubra ('Illinois Everbearing')* *Morus nigra (Black mulberry)* *Morus rubra (red mulberry)* *Morus sp. (Mulberry)* *Eugenia uniflora (Surinam cherry)* *Eriobotrya japonica (loquat)* *Lycium barbarum (goji berry)* *Ampelopsis glandulosa (porcelain berry)*
Secondary hosts – field collected	These hosts are considered secondary hosts, as only susceptible if fruit is ripe and or damaged. No reported commercial damage has been found in these hosts	*Actinidia chinensis* (Chinese gooseberries) *Actinidia arguta* (hardy kiwi) *Arbutus unedo* (Strawberry tree) *Citrus sinensis* (orange) *Citrus x paradisi* (grapefruit) *Diospyros kaki* (persimmon) *Diospyros virginiana* (American persimmon) *Elaeagnus multiflora* (Cherry silverberry) *Ficus carica* (Common fig, 'Brown Turkey' and 'Mission') *Malus domestica* (apple) *Malus pumila* (Paradise apple) *Murraya paniculata* (Orange jasmine) *Musa acuminata* (banana)	*Prunus maritima* (beach plum) *Pyrus communis* (pear) *Pyrus pyrifolia* (Asian pear, nashi pear) *Ribes rubrum (Redcurrant)* *Ribes sanguineum (redflower current)* *Rosa acicularis* (Prickly wild rose) *Rosa canina* (dog rose) *Rosa glauca* (Redleaf Rose) *Rosa pimpinellifolia* (burnet rose) *Rubus spectabilis* (salmon berry) *Sapindus spp.* (soapberry) *Solanum lycopersicum* (Tomato)
Wild non-crop hosts - field collected	A variety of plants are reported as SWD hosts. This included ornamental and wild hosts	*Alangium platanifolium* (alagium)* *Amelanchier lamarckii* (juneberry)* *Amelanchier ovalis* (snowy mespilus) *Arum italicum* (Italian lily) *Camellia japonica* (Japanese camellia) *Cornus alba* (white dogwood) *Cornus amomum* (silky dogwood) *Cornus controversa* (Giant dogwood) *Cornus foemina* (stiff dogwood) *Cornus kousa* (Japanese dogwood) *Cornus mas* (Cornelian cherry) *Cornus racemosa* (grey dogwood) *Cornus sanguinea* (common dogwood) *Cornus sericea* (red-twig dogwood) *Cotoneaster franchetii* (Franchet's cotoneaster) *Cotoneaster lacteus* (Milkflower cotoneaster) *Cotoneaster rehderi* (Bullate cotooneaster)* *Crataegus chrysocarpa* (Fireberry Hawthorn)* *Crataegus monogyna* (common hawthorn)	*Prunus cerasifera* (Cherry plum) *Prunus laurocerasus* (Cherry laurel) *Prunus lusitanica* (Portuguese-laurel) *Phytolacca esculenta* * *Phytolacca americana (American pokeweed)* *Prunus mahaleb* (mahaleb cherry) *Prunus padus* (bird cherry) *Prunus serotina* (black cherry) *Prunus spinosa* (blackthorn) *Pyracantha sp.* *Rhamnus alpina* (Alpine buckthorn)* *Rhamnus cathartica* (common buckthorn)* *Rosa rugosa* (wild rose, rose hips) *Rubus caesius* (European dewberry)* *Rubus crataegifolius* (Various wild raspberries) *Rubus fruticosus* (blackberry, marionberry) *Rubus microphyllus* (wild raspberry) *Rubus phoenicolasius* (Wineberry) *Rubus saxatilis* (stone bramble) *Rubus spectabilis* (Salmonberry) *Rubus ulmifolius* (elmleaf blackberry)

HOST CATEGORY	DESCRIPTION	SPECIES	
		Daphne mezereum (mezereum) *Elaeagnus umbellata* (Autumn olive) *Fragaria vesca* (wild strawberry) *Frangula alnus* (alder buckthorn) *Frangula purshiana* (Cascara buckthorn)* *Gaultheria shallon* (salal) *Gaultheria x wisleyensis* *Hippophae rhamnoides* (sea buckthorn) *Lindera benzoin* (spice bush) *Lonicera alpigena (*alpine honeysuckle)* *Lonicera caerulea* (blue honeysuckle) *Lonicera caprifolium* (Honeysuckle)* *Lonicera ferdinandii* (korean honeysuckle)* *Lonicera japonica* (Japanese honeysuckle) *Lonicera nigra* (black-berried honeysuckle)* *Lonicera sp.* *Lonicera xylosteum* (fly honeysuckle)* *Mahonia aquifolium* (Oregon grape) *Mahonia sp.* *Malus baccata* (Siberian crab apple) *Paris quadrifolia* (herb-paris)* *Parthenocissus quinquefolia* (Virginia creeper) *Photinia beauverdiana* (Christmas berry) *Photinia prunifolia* (Black Chokeberry) *Photinia villosa* (oriental photinia) *Polygonatum multiflorum* (Solomon's-seal) *Potentilla indica* (mock strawberry)	*Sambucus ebulus* (dwarf elder) *Sambucus nigra* (black elder, European elder) *Sambucus nigra spp. cerulea* (blue elderberry) *Sambucus racemosa* (Red Elderberry) *Sarcococca confusa* (Sweet box) *Sarcococca hookeriana* (Himalayan sweet box) *Solanum dulcamara* (bitter sweet nightshade) *Solanum nigrum* (black nightshade) *Sorbus aria* (common whitebeam) *Sorbus aucuparia* (mountain ash) *Symphoricarpos albus* (Common snowberry) *Symphoricarpos spp*. (snowberry) *Tamus communis* (black bryony)* *Taxus baccata* (common yew) *Taxus cuspidata* (Japanese yew)* *Vaccinium myrtillus* (bilberry) *Vaccinium oldhamii* (unnamed)* *Vaccinium praestans* (Kamchatka Bilberry) *Viburnum lantana* (wayfaring tree) *Viburnum rhytidophyllum* (Leatherleaf viburnum) *Solanum villosum* (red nightshade) *Prunus avium* (Various ornamental and wild cherries)

*= not present in Australia

2.3 Signs and symptoms

SWD larvae cause damage by feeding on the pulp inside fruit and berries. Infested fruit show small scars and indented soft spots on the surface, which is left by the ovipositing females. The infested fruit begins to collapse around the feeding site causing a depression or visible blemish on the fruit, sap exudates may also be evident. The oviposition scar exposes the fruit to secondary attack by pathogens and other insects, which may cause rotting (Hauser et al. 2009). If the attack rates are high by SWD, the entire fruit can collapse. Signs of infestation may be confused with normal ageing of mature fruit. However, fruit that has been attacked by SWD shows rapid softening and wrinkling within a few days after egg laying (Table 5). SWD preferentially attack fruit prior to harvest, but they can also attack harvested fruits. Look for signs of SWD on fresh fruit in packing houses. Examples of damage to cherries (Figure 2), raspberries (*Figure 3*), strawberries (Figure 4), blueberries (Figure *5*), are shown below.

Other signs of attack include premature fruit drop, the presence of larvae and pupae within fruit and adult fruit flies on fruit and in traps. The presence of larvae in intact fruit prior to harvest should alert suspicion to possible SWD infestation.

Factsheets with more information on what to look for in the field can be found at the following websites:

- http://www.planthealthaustralia.com.au/pests/spotted-winged-*Drosophila*/
- https://www.dpi.nsw.gov.au/biosecurity/plant/insect-pests-and-plant-diseases/spottedwing-*Drosophila*
- http://www.planthealthaustralia.com.au/wp-content/uploads/2016/05/Spotted-winged-*Drosophila*-FS-Blueberries.pdf
- http://www.planthealthaustralia.com.au/wp-content/uploads/2013/01/Spotted-winged-*Drosophila*-FS-Cherry.pdf
- http://www.planthealthaustralia.com.au/wp-content/uploads/2013/09/Spotted-winged-*Drosophila*-FS-Rubus.pdf
- http://www.planthealthaustralia.com.au/wp-content/uploads/2013/11/Spotted-winged-*Drosophila*-FS-Viticulture.pdf
- https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/

Table 5: summary of main damage for key crop

CROP	DAMAGE AT EGG LAYING	DAMAGE 3 DAYS AFTER EGG LAYING	DAMAGE AFTER MORE THAN 5 DAYS AFTER EGG LAYING
Raspberries	- Breathing tubes visible under 30X magnification - oviposition scar visible	- Raspberries show damage quickly. The skin wrinkles and fruit becomes juicy. Scarring and collapse of berry may occur as early as 1–2 days following infestation - impacted development of individual druplets - Larval holes allow fruit juice to escape the berry	- Dark scarring apparent - Visible larvae - Rotting of fruit
Blueberries	- Breathing tubes visible under 30X magnification - oviposition scar visible	- Larval holes allow fruit juice to escape the berry, and soft areas become pronounced - Fruit wrinkling	- Collapsed fruit - Visible larvae - Rotting of fruit
Strawberries	- Oblong egg under the surface visible	- Quick deterioration. The skin wrinkles and fruit softens; mould may appear ~3 days after infestation.	- Visible larvae - Rotting of fruit

CROP	DAMAGE AT EGG LAYING	DAMAGE 3 DAYS AFTER EGG LAYING	DAMAGE AFTER MORE THAN 5 DAYS AFTER EGG LAYING
Cherries	- Breathing tubes visible under 30X magnification - Oviposition holes often associated with black necrotic scar tissue	- Soft spots at oviposition sites	- Collapsed berries - Emerging prepupal stages and damage directly under the cherry surface - Visible larvae - Rotting of fruit
Grapes	- Breathing tubes visible under 30X magnification - oviposition scar visible	- Dark area in light fruit - Light area in darker fruit - Infested berries where turgor pressure caused expulsion of liquid through oviposition hole	- Collapsed fruit - Visible larvae - Rotting of fruit

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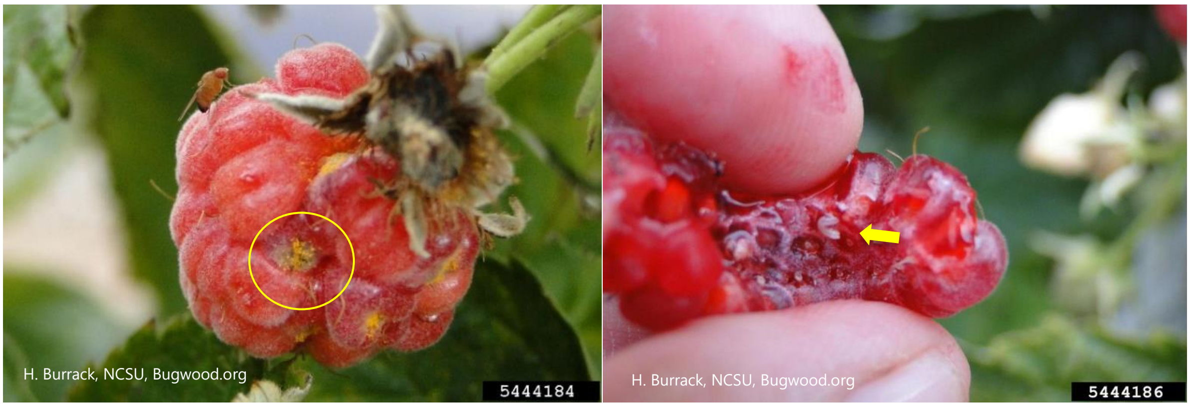
Figure 2: External damage to cherries(left), oviposition scars highlighted by red arrow and secondary rotting in cherry fruit (right)



H. Burrack, NCSU, Bugwood.org

H. Burrack, NCSU, Bugwood.org

Figure 3: Damage to raspberries including impacted development of individual druplets highlighted in yellow circle (left), larva feeding on flesh indicted by yellow arrow(right)

Figure 4: Damage to strawberries with larvae present (left), eggs highlighted with yellow arrow, in strawberry flesh (right)

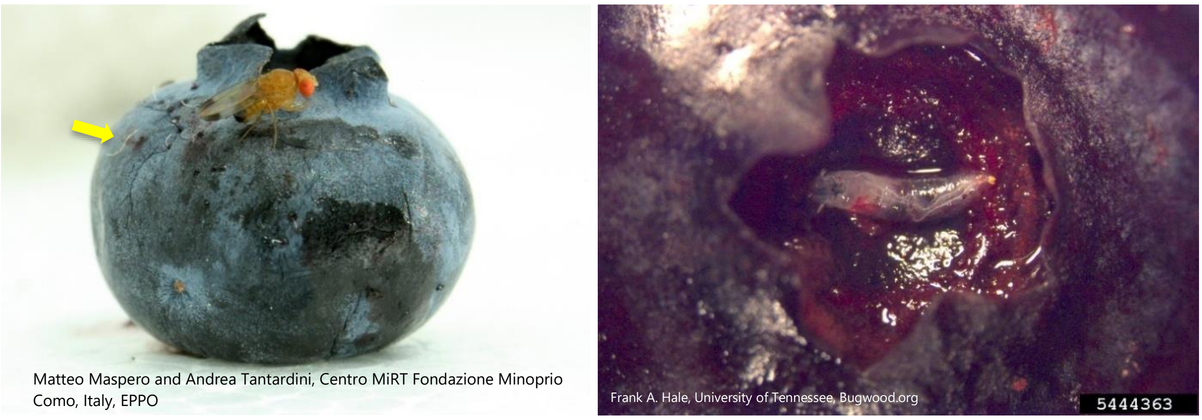


Figure 5: Damage to blueberries with oviposition sites Note the stipples caused by oviposition with filaments from the eggs protruding (left). larva feeding on a blueberry (right)

2.4 Diagnostic Information

Rapid and reliable diagnostic protocols for all life stages is vital for the effective detection and subsequent response to this species. Historically, in some instances, the response to SWD was delayed due to misidentification – the fly looks similar to a number of other species present in some countries. In California SWD was initially thought to be *Drosophila biarmipes* (Hauser 2011). The 'first detection' in Chile was disproven following the realisation that the specimens collected were not in fact SWD (EPPO 2016).

SWD may be suspected based on fruit symptoms, however, because SWD larvae closely resemble other Drosophilidae and many *Drosophila* species have larvae that are commonly found in rotting fruit, definitive identification of SWD requires microscopic examination of well-preserved adult specimens. Morphological diagnosis to a species level requires adult flies. Adults can be collected by sweep netting, traps or collecting fruit with larvae in them and allowing the larvae to develop into adults. Alternatively, molecular tools can be used to identify both larvae and adult flies.

An EPPO diagnostic protocol for spotted wing drosophila (EPPO 2013) is available and should be referred to for the diagnosis of suspected SWD. Further to this, a draft diagnostic identification protocol has been produced for Australia (Blacket et al. 2015), and diagnostic information is also available on Fruit Fly ID Australia https://fruitflyidentification.org.au/species/*Drosophila-suzukii*/#gallery.

2.4.1 Phenotypic identification

The adult stage is the only life stage that is considered to be reliable for morphologically based taxonomic identification (Figure 6). While in-field observations may be enough to indicate that an unusual pest is present, morphological identification of SWD to species level requires a high magnification binocular microscope. SWD has several features that distinguish it from most other *Drosophila* species. The most prominent of these are the distinctive dark spots towards the apex (end) of the wing, though these are only present on males of the species (Figure 7) and winter morphs may not display them. Similar apical spots are also observable on *D. biarmipes* (present in India) and *D. subpulchrella* (present in China and Japan). Less distinct spots are also observable in *D. pulchrella* (known from China). Notably, none of these species occur within Australia and the observation of any male *Drosophila* specimens with spots on the wings would be cause for concern.

Females are very similar in appearance to other *Drosophila* species that might be observed, apart from the ovipositor. In SWD the oviscape valve of SWD, is larger in area than most other *Drosophila* and has thick, heavily sclerotized bristles near the distal tips of the valve (Figure 8). However, as the ovipositor is between 0.25 and 0.5mm long, observing these features is not possible without at least a high-powered hand-lens. Similar sclerotization is observed in *D. pulchrella* and *D. subpulchrella*. Of the species already present in Australia, only *D. immigrans* has similar, though much less distinct, sclerotization. In comparison to *D. subpulchrella*, a closely related species, female SWD have more modified bristles on the lateral side of the oviscape valve as well as a more streamlined knife-like or blade-like shape as measured by the oviscape valve's length-to-width ratio (Atallah et al. 2014).

Figure 6: Male (left) and female (right) SWD (source Mark Blacket accessed at https://fruitflyidentification.org.au/species/Drosophila-suzukii/)

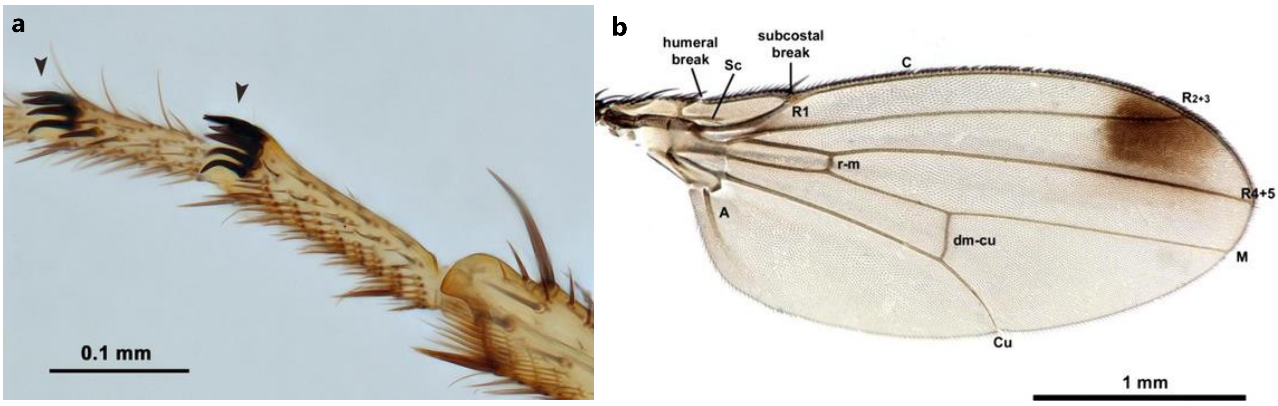


Figure 7: Drosophila suzukii- a) sex combs on first and second tarsomere of male's forelegs. b) right wing of a male with indicated veins and distinct spot (source EPPO 2013 PM 7/115 (1) Drosophila suzukii)

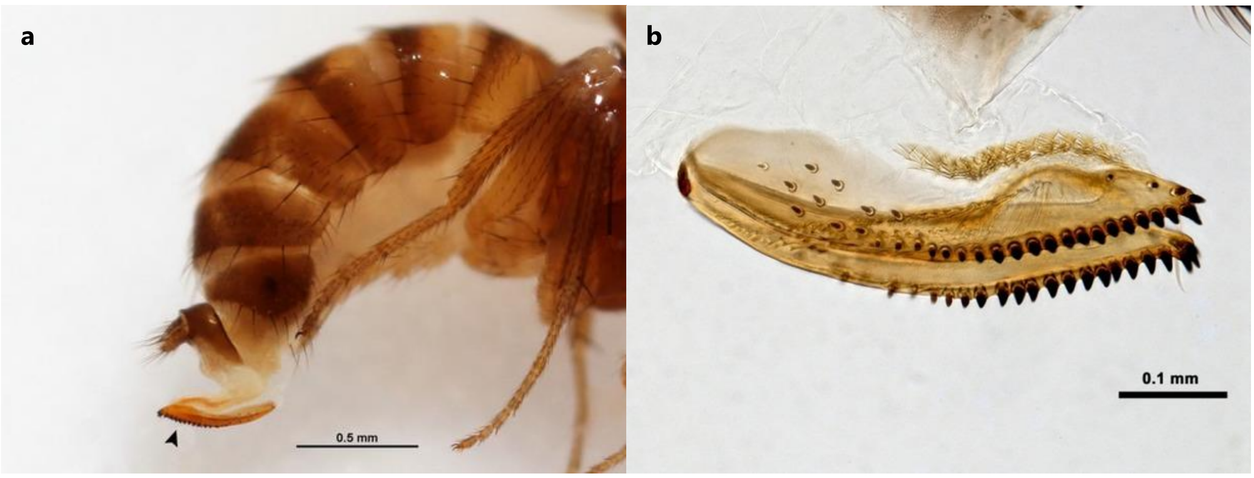


Figure 8: Drosophila suzukii - a) female with strongly sclerotized saw-like ovipositor. b) Drosophila suzukii - ovipositor with strong black teeth on valve margins (source EPPO 2013 PM 7/115 (1) Drosophila suzukii)

2.4.2 Molecular identification

Four molecular identification methods are currently in use for SWD, including DNA Barcoding

- PCR-RFLP. Developed and validated by Kim et al. (2014) to differentiate between twenty-one *Drosophila* species. This test is based upon digesting a fragment of the COI gene using the restriction enzyme Msp-1.
- HRM Real Time PCR. Developed and validated by Dhami and Kumarasinghe (2014). It provides a quick, high-throughput, identification method based upon fluorescence-based real-time PCR. High Resolution Melt assays are needed to distinguish the closely related *Drosophila* species
- Multiplex PCR. This species-specific primer multiplex PCR test was developed by Murphy et al. (2015), where they validated it on nine different species of *Drosophila* and 19 populations of SWD. It has been developed to differentiate between SWD and *D. subpulchrella*.
- DNA barcoding has been employed by to confirm SWD in Europe (Calabria et al. 2012) and Germany (http://ibol.org/dna-barcode-confirms-harmful-pest-has-landed-in-germany/).

Currently in Australia the following is being conducted

- Assessment of metabarcoding as a high-throughput trap catch identification approach for SWD surveillance, and LAMP for in-field SWD identification.
- Evaluation of commercially available SWD traps for suitability in metabarcoding-based trap surveillance.

2.4.3 SWD diagnostic considerations

SWD is very similar with endemic insects and can be easily confused with several similar *Drosophila* species common in rotten fruit in Australia, because of this identification may be problematic. Further to this, traps and lures for SWD do not have a high specificity, thus contain a large volume of by-catch which can complicate diagnostics. Considerations when assessing samples of suspected SWD for diagnostics include:

- The presence of spots on the wings of adult males is highly distinct and would not be observed in any other species present within Australia or New Zealand.
- Distinctive morphology of the dark combs on the basal tarsal segments. Male *D. melanogaster* and *D simulans* are superficially similar to SWD in usually possessing dark tipped abdomens but they differ in the morphology of the combs on the basal tarsal segments and in having non-spotted wings.
- The well-developed and sclerotised ovipositor on adult females is also an important, though not entirely unique characteristic that could be observed with hand lenses (Figure 9). Female *D. immigrans* are superficially similar in the morphology of the ovipositor, however, in female SWD the ovipositor is strongly sclerotized with robust teeth along the lower half towards the ovipositor tip. The relative size of the ovipositor compared with the spermatheca also differs substantially between these two species.
- Immature stages (eggs, larvae, pupae) cannot be differentiated from closely related *Drosophila* species in Australia, except through molecular methods, or by rearing them into adults.
- Large by-catch in collected in traps has a significant impact on diagnostic capacity
- Liquid traps need to pe processed quickly as to avoid samples degradation.

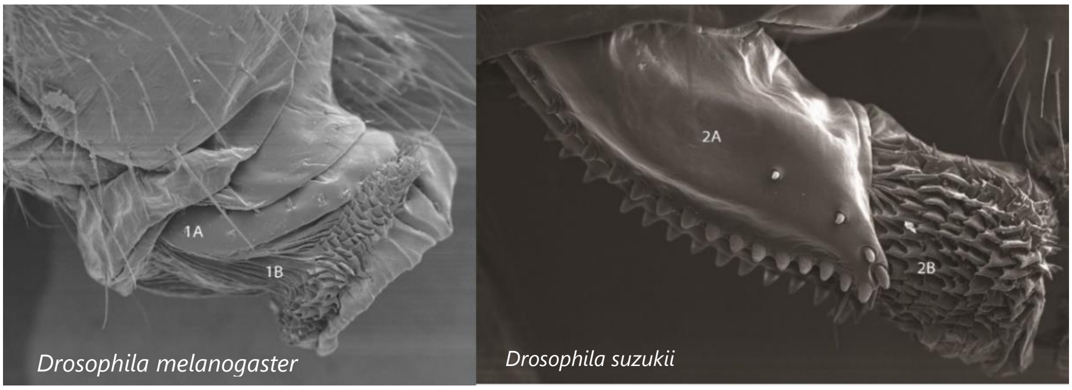


Figure 9: (Left) Drosophila melanogaster oviscape valve (1A) lacking sclerotized teeth and eversible membrane (1B) with small band of denticles. (Right) Drosophila suzukii oviscape valve (2A) showing extensive sclerotized teeth and eversible membrane (2b) with prominent denticles. Unpublished images from Dave Bellamy (Plant & Food Research) and Dennis Margosan (USDA-ARS).

2.5 Geographic distribution

Little is known about the geographic origin of SWD. The insect is thought to be native to Asia, including China, Japan and Korea (Walsh et al. 2011). The first report of SWD is from Japan where larvae were found in pre-harvest cherries (*Prunus avium*) in 1916 in Yamanashi Prefecture, though SWD was not described until 1931 (MPI 2012, Asplen et al. 2015). SWD is also reported from Taiwan, Pakistan, Myanmar, Nepal, Thailand, Far East Russia and India (MPI 2012, Asplen et al. 2015).

2.5.1 Incursion history of SWD

Much can be learnt by reviewing previous incursions of SWD. The information gleaned can assist with risk analysis and can aid readiness efforts for countries that consider the pest a threat. SWD has spread from its native range in Asia to over 30 countries in North America, South America and Europe (see Figure 10 and Appendix 2). It is important to note that no country has eradicated SWD and it appears to spread very rapidly after initial detection.

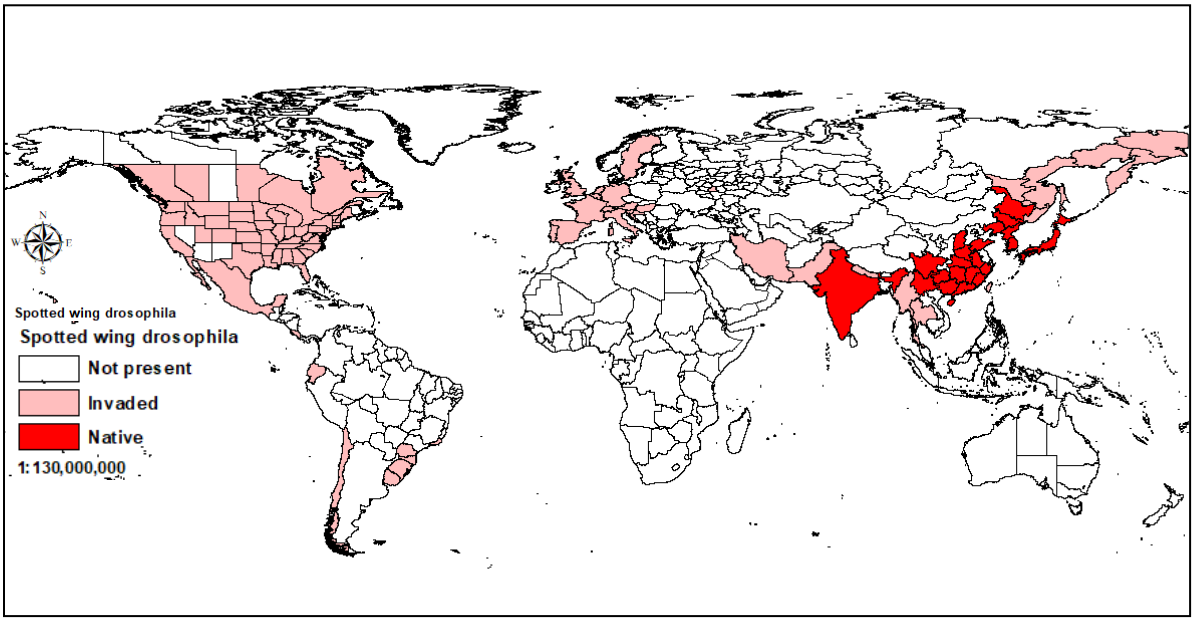


Figure 10. Global distribution of SWD as of 2018. Source: Ministry for Primary Industries (https://www.mpi.govt.nz/protection-and-response/finding-and-reporting-pests-and-diseases/priority-pests-plant-aquatic/horticultural-pests/spotted-wing-Drosophila/)

Spread to North America

The first detection of SWD in North America was confined to the Hawaiian Islands, but once it reached the continental mainland, spread was rapid (Figure 11). Significant damage has been seen in North America as population numbers have increased and range expansion has occurred. SWD was recorded for the first time in North America in Hawaii on the island of Oahu in 1980 and then on several other Hawaiian islands (Hauser 2011). The second detection occurred on mainland USA in California in 2008, though the response to this detection was delayed somewhat due to misidentification as *Drosophila biarmipes* Malloch (Hauser 2011). SWD larvae were found in raspberry crops and to a lesser degree in strawberry crops. Just one year later (in 2009) SWD had spread to over 20 counties in California and was also found along the west coast in Oregon and Washington, and in Florida. Public awareness and monitoring initiatives in 2010 resulted in detections of SWD adults along the east coast (Hauser 2011).

In Canada, SWD was first found in British Columbia in 2009. It was then detected in Alberta, Manitoba, Ontario and Quebec in 2010 (Asplen et al. 2015).

SWD was first detected in Mexico in 2011 (Lee et al. 2011) in Michoacán State. The pest rapidly expanded to other states, namely Colima, Guanajuato, Aguascalientes, State of Mexico, and Baja California (Lasa and Tadeo 2015).

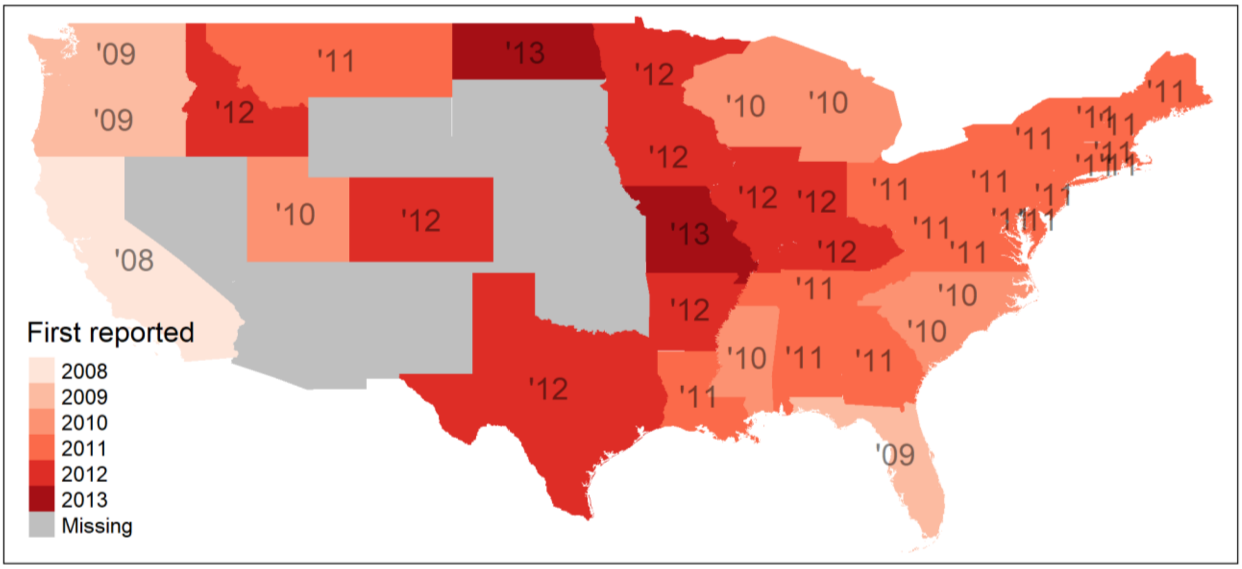


Figure 11: Reported spread across the United States mainland using state level data reported in Ørsted and Ørsted (2019). Numbers in states represent the abbreviated year of first report.

Spread to Europe

The first point of detection in Europe is unclear. Some authors suggest Spain was the first location, others Italy, and some hypothesise that southern France was the likely spreading centre prior to 2008 (Cini et al. 2014). Regardless, SWD is now present throughout much of Europe (Figure 12). Various monitoring programmes in the region seem to suggest population growth and spread occurred rapidly within countries, with the period from first detection to widespread occurrence spanning just a few years in many cases (Table 6)

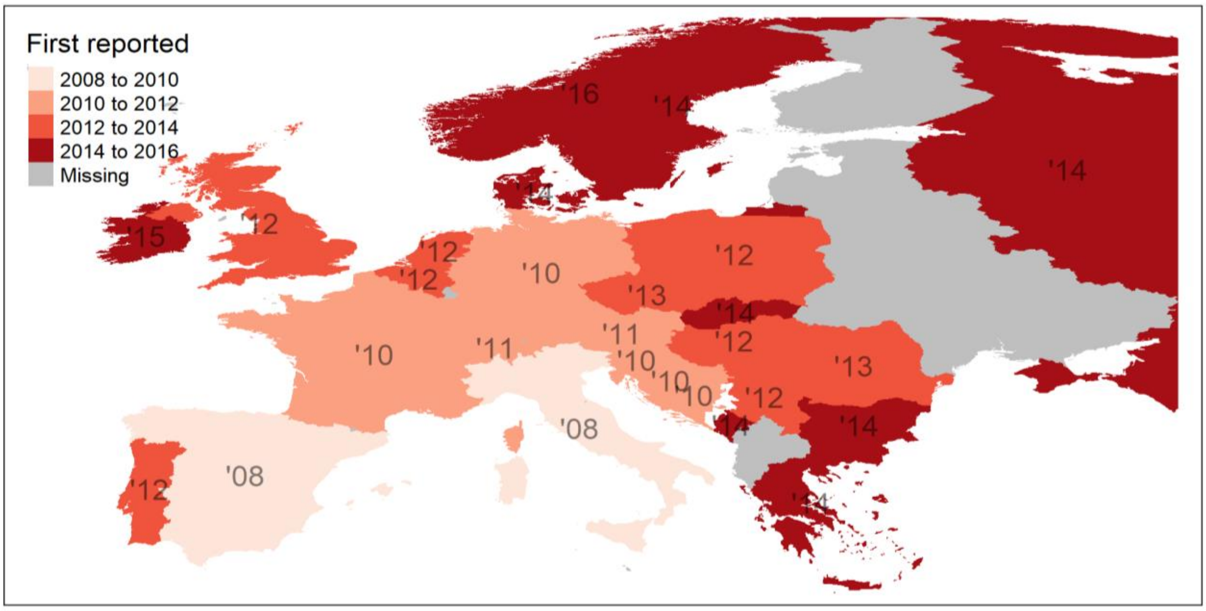


Figure 12: *Reported spread across the European mainland using state level data reported in* (Ørsted and Ørsted 2019) *Numbers in states represent the abbreviated year of first report*

Table 6: Summary of incursion history throughout Europe presented chronologically

COUNTRY	SWD INCURSION HISTORY
Spain	First detected in Spain in a pine forest in Rasquera in autumn 2008 (Calabria et al. 2012). Ten males and two females were collected from either fermented banana traps or fermented beer. SWD was not present in samples collected from southern Spain at the same time, nor was it present in samples collected from Barcelona the previous year (2007) (Calabria et al. 2012). In 2011, it was found in traps in fruit crops, and apparently also at a wholesale fruit market. By 2013 the pest was found in cherry orchards in north western Spain in areas that had been sampled since 2010 (Asplen et al. 2015).
Italy	Traps deployed in Tuscany in 2008 caught the first specimens in Italy (Cini et al. 2012). The pest was first reported in 2009, however, when the catches from the 2008 traps were inspected, SWD was found (Asplen et al. 2015).
France	In late August/early September of 2009, SWD was first detected in France in Montpellier and Alpes Maritimes, however, it was absent from samples collected in the north of France (Calabria et al. 2012).
Slovenia	First detection was reported in October 2010 (Seljak 2011).
Croatia	First found in Croatia in apple cider vinegar-baited traps in a peach orchard in the Dalmatia region in 2010. Monitoring in 2013 confirmed that the pest was present and widespread. It has been detected in urban areas and horticultural crops in coastal areas, inland and on two islands (Bjelis et al. 2015).
Germany	The first detection was in September 2011, despite monitoring the previous year (Vogt et al. 2012, Asplen et al. 2015). Larval infestations were found in cherries, raspberries, blackberries, elderberries, and grapes (Vogt 2014). High numbers of adults were captured post-harvest in in both orchards and in wild areas (Asplen et al. 2015, Briem et

COUNTRY	SWD INCURSION HISTORY
	al. 2015).
Belgium	First reported in Ostend in September 2011. A single male was captured near the harbour in Zerbrugge (Mortelmans et al. 2012). The pest was detected again in 2012 in cherries, plums, strawberries, raspberries, and blueberries (Asplen et al. 2015).
Austria	The first report occurred in September 2011. The pest was found in three states infesting raspberries, elderberries, and hardy kiwi (kiwiberries). Nationwide monitoring in 2012 found that SWD was concentrated in the west and south of the country, but by 2013 it was shown that SWD was distributed throughout Austria (Asplen et al. 2015).
Switzerland	First confirmed in July 2011. Monitoring using apple cider vinegar baited traps found that SWD was present throughout the country, from fruit production areas at low altitude to the bush line. Pest pressure in Switzerland has been observed to increase through the season from May to November (Asplen et al. 2015).
Netherlands	A SWD-specific survey conducted in the Netherlands in 2012 detected the pest at eight locations, including forested sites. The survey utilised traps baited with apple cider vinegar and red wine. Monitoring in 2013 did not detect SWD until mid-August, with the first trap captures in cherry orchards near a sales point for imported fruit. High rates of infestation have been seen in elderberry (*Sambucus* spp.) crops in the Netherlands (Helsen et al. 2013, Asplen et al. 2015).
Portugal	First identified in July 2012 in Odemira and Algarve in the westernmost part of the Iberian Peninsula (Asplen et al. 2015). The detection was in a commercial raspberry greenhouse (EPPO 2012a).
United Kingdom	The first report was in September 2012 (EPPO 2012b, Asplen et al. 2015). A national monitoring programme deployed the following year in soft and stone fruit orchards in England and Scotland detected SWD in August, with captures increasing through late autumn and winter. More SWD were trapped in woodland compared to crops (Asplen et al. 2015).
Hungary	The first detection was in September 2012 SWD was detected at a highway rest stop (Kiss et al. 2013, Lengyel et al. 2015). The detection was the result of a nation-wide invasive pest survey which involved placement of bottle traps containing apple cider vinegar along highways (Kiss et al. 2013). A countrywide trapping programme for SWD followed, focussing on highway rest areas and commercial orchards. SWD was found in five locations along highways, but was not detected in rural orchards (Lengyel et al. 2015). Subsequent surveys indicated that SWD had become relatively widespread by the end of 2014, with damage reported in raspberry, plum and nectarine orchards (Kiss et al. 2016).
Bosnia and Herzegovina	Recorded at several locations in Bosnia and Herzegovina in 2013 (Ostojic et al. 2014, Asplen et al. 2015).
Montenegro	First found in 2013 along the coast and in the Podgorica area of Montenegro in Tephri traps (Asplen et al. 2015, Radonjic and Hrncic 2015).
Romania	The first detection occurred in Bucharest in 2013. Tephri traps (attractant not stated) set in wild blackberry as part of a national fruit fly trapping programme captured adult SWD (Chireceanu et al. 2015).

COUNTRY	SWD INCURSION HISTORY
Serbia	A survey of fruit conducted in October and November 2014 revealed SWD in four districts in Serbia. The pest was present in raspberry, blackberry, fig and grape and populations were established at altitudes from 70-800m (Toševski et al. 2014).
Sweden	The first record is from the county of Scania (Skåne) in southern Sweden where it was detected in August 2014 (Manduric 2017). The specimens were found in apple cider vinegar-wine-baited traps that had been placed in mixed shrubby vegetation near grocery stores in an urban area. SWD was also in two berry plantations later that same year less than 50 km from the initial find (Manduric 2017). Inventory work in crops in 2015 found further flies in Scania county, but they were absent from other regions. However, SWD was found in three additional regions in 2016 in raspberries, blackberries, blueberries, strawberries, elderberries, red currants, cherries, plums and grapes (Manduric 2017).
Ukraine	Initially found near Yalta, an important port on the Black Sea, during biodiversity surveys that used smashed fermented apples and wheat beer as lures in 2014 and 2015.The same sampling localities had been surveyed for *Drosophila* species every year since 2005 (Lavrinienko et al. 2017).
Turkey	First collected from infested strawberry plants from the garden of the Department of Horticulture at Atatürk University in Erzurum (Orhan et al. 2016). The damaged strawberry crops were observed on September 2014 and samples were taken into the lab to rear out the larvae, which were subsequently identified as SWD (Orhan et al. 2016).
Poland	First detected at the end of 2014, despite active searching for the pest in the years prior. Fruit monitoring was conducted in plantations (e.g. blueberries) in 2012 and 2013 and observations were carried out at a wholesale market in Bronisze near Warsaw where domestic and imported fruit was stored and traded, SWD was not detected. When adults were finally detected in 2014, they were captured in blueberries in the west and raspberries in the south (Asplen et al. 2015).
Greece	In 2013, SWD was reported in the Ioannina region of Greece, but this initial detection of an adult male in a mixed berry orchard trap remained unconfirmed (Asplen et al. 2015). This initial report was followed by a detection on Crete in March 2014, where five specimens were caught in a beer trap in a shrub in a low scrubland area (Asplen et al. 2015, Máca et al. 2015).
Bulgaria	First appeared in Southwestern Bulgaria in September 2014. The pest was detected via trapping (lure not stated) close to cherry trees (Asplen et al. 2015, EPPO 2015a).
Czech Republic	First confirmed in fruit production areas in September 2014. The detections were the result of trapping efforts with apple cider vinegar-baited traps (EPPO 2014a, Asplen et al. 2015).
Slovakia	The pest was first found in October 2014 in Slovakia in a trap (likely apple cider vinegar) at a farm in Levice District. The site had apple and plum trees present and grapes were processed there, though no damage was observed (EPPO 2014b, Asplen et al. 2015).
Ireland	The first detection was in August 2015 in a trap located by the packing house on a Dublin farm. The pest was trapped in hedgerows surrounding a soft fruit and stone fruit growing area in the weeks following the initial detection (EPPO 2015b). While the use of a pheromone trap was indicated in the report, no further evidence of a

COUNTRY	SWD INCURSION HISTORY
	pheromone trap for the detection of adult SWD has been found. This is likely the incorrect use of the word pheromone. Local authorities recommend the use of vinegar-based pheromone traps.
Cyprus	Traps (lure not stated) placed in commercial crops in Nicosia district caught the first SWD specimens in Cyprus in 2017 (EPPO 2017a).

Spread to South America

South America is the latest continent to have been invaded by SWD, with the first validated detection in 2013. A number of South American countries currently only have localised populations, rather than the widespread distribution seen in many European and North American countries. There are unconfirmed reports of SWD in Ecuador (Hauser 2011).

Table 7: Summary of incursion history in each country in South America presented chronologically.

COUNTRY	SWD INCURSION HISTORY
Brazil	The first occurrence of SWD in Brazil was recorded in Santa Catarina state in February 2013. Samples were collected with banana-baited traps in nearby regions through to May 2013 (Deprá et al. 2014). During 2014, SWD was only collected from regions <400 km from the coast (Deprá et al. 2014). SWD has since spread to numerous other states and has been confirmed as present in the highlands of Espírito Santo (Zanuncio-Junior et al. 2018). The pest is associated with blackberry and sometimes papaya and strawberry (Zanuncio-Junior et al. 2018). Human mediated spread has been documented in Brazil – in 2014 researchers purchased fruit from a Sao Paulo grocery store and reared SWD from blueberries which had been produced in a different state (Santa Catarina) (Vilela and Mori 2014).
Uruguay	Banana-baited traps and over-ripe or damaged blueberries collected from the ground revealed SWD for the first time in Uruguay in 2013 (González et al. 2015, EPPO 2016).
Argentina	One of the more recent countries to be invaded by SWD is Argentina. It appears that the pest was first detected in Buenos Aires province in 2015 (Lavagnino et al. 2018). It is now present in the Mesopotamia region, Tucumán and Patagonia region, which constitutes the southernmost record of SWD in South America. Flies in Argentina have been captured near orange, mulberry and raspberry plantations, as well as from an unknown host which may be the native *Opuntia* cactus (prickly pears) (Lavagnino et al. 2018).
Chile	In a paper published in 2015 SWD was reported near the principle port of Valparaíso (Medina-Muñoz et al. 2015), however, the identification was shown to be incorrect and as such the record was denied by the Chilean NPPO. The first confirmed report of SWD in Chile was in 2017. Traps paced in blackberry bushes caught specimens in La Araucanía region, near an international road which leads to a border point (EPPO 2017b). Since the initial detection SWD has been caught in Los Lagos and Los Ríos regions.

3 RISK PATHWAYS AND POTENTIAL IMPACTS

3.1 Entry potential and pathways

This section builds on previous risk analyses through a quantitative analysis on the risk of trade pathways that utilises the current global distribution of SWD, pest environmental suitability of import locations, association with commodities, and volumes of imported associated commodities.

3.1.1 Entry potential

Human-mediated spread of pests is emerging as a major dispersal mechanism in modern biological invasions (Hulme 2009; Hudgins et al. 2017). SWD is no exception with the movement of plant products destined for human consumption playing an important role in its global invasion. Much of the international literature mentions human-mediated transport of fresh produce as the key means of spreading SWD into new countries and regions within countries. Globally, the consumption of plant-derived goods represents a major pathway for pest introductions. An estimated 87% of pest interceptions at the United States border between 1984 and 2000 were associated with consumable goods such as fresh fruit and vegetables (McCullough et al. 2006).

There have been numerous first detections near important sea ports, for example Zeebrugge in Belgium (Mortelmans et al. 2012) and Yalta in Ukraine which is a major tourism and commercial port (Lavrinienko et al. 2017). These detections near ports may indicate a higher risk of entry and establishment near seaports but also tend to be associated with large human populations. There have also been first detections near facilities where imported fruit arrives or is sold from, for example the detection near a grocery store in Sweden (Manduric 2017), by an imported fruit sales point in the Netherlands (Helsen et al. 2013) and in trees near shops and restaurants in tourist areas in Croatia (Bjelis et al. 2015). The above examples from previous incursions support the idea that movement of infested fruit (commercial or otherwise) is the most probable pathway for long-distance movement to new continents, whether by air or sea.

In a study by Fraimout et al. (2017), a phylogenetic approach was used to infer probable spread pathways. Southeast China and Hawaii together were identified as the most likely sources of multiple incursions into western North America, which then in turn served as source populations for incursions in eastern North America. The most probable source of European populations was northeast China, with some evidence of limited gene flow from the eastern United States (Fraimout et al. 2017). In both cases, after the initial incursion, spread occurred rapidly throughout the continent suggesting that pre-border biosecurity is an essential component in minimising the risk of spread and establishment to other countries. This requires the identification and prioritised management of high-risk pathways for preventative measure and appropriate allocation of surveillance resources for early detection and preparedness (Hulme 2009).

Natural pathways of spread into Australia are likely to be extremely low given Australia's natural geographic isolations and the low rates of natural dispersal estimated in a recent study on post-border spread (Maino 2020b).

International travel and movement of goods between countries pose the most significant risk of this pest being introduced into Australia. However, due to current import and phytosanitary restrictions on exporters of high-risk commodities; requirements for the declaration of any plant-derived goods associated with passenger movements and mail and the low likelihood of natural spread; this risk is greatly mitigated. Quarantine and movement controls are discussed further in Section 5.1.2.

3.1.2 Pathways

Potential pathways analysis of SWD into Australia has been conducted by **cesar** and can be found at https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/. Potential pathways were identified through a quantitative analysis of Australian import volumes and seasonality, the global species distribution, commodity susceptibility, and ecoclimatic suitability. This analysis has not considered variation in phytosanitary procedures in place at importing and exporting locations, which was beyond the scope of this analysis.

3.1.2.1 Fruit

The most likely pathway for SWD to enter is the importation of fruits of host species. Fresh fruit pathways into Australia are heavily regulated to manage biosecurity risk from pests such as SWD. Commercial produce entering Australia via sea and air require strict biosecurity measures with importation by travellers prohibited. Despite these restrictions there may still be potential fresh fruit pathways which include:

- Shipments of commercial produce
- Airfreighted commercial produce
- Air passengers
- Passengers arriving by sea
- Mail

SWD has a wide host range, nevertheless a distinction should be made between preferred hosts that are regularly found to be infested and thus likely to be major pathways and other secondary or wild non-crop hosts. Regarding Australian imports of fresh plant products, the commodities of most interest (primary/preferred hosts) are caneberries, blueberries, strawberries, grapes, summerfruit, cherries and currants. These commodities are hosts prior to or at harvest so are potentially traded when containing larvae.

Following the national Pest Risk Analysis (PRA) (Department of Agriculture Fisheries and Forestry Biosecurity 2013), additional traded commodities have since been shown to support SWD including pome fruit and citrus, which are known to be a viable host when the fruit is overripe or skin is damaged (Harris et al. 2014; Stewart et al. 2014). These additional hosts have been included in the potential pathways analysis of SWD into Australia conducted by **cesar.** Mushrooms were also considered as a secondary host following research that found mushrooms and some animal faeces can serve as a viable host (Stockton et al.; Wallingford et al. 2018). While tomatoes have also been shown to be a viable host when skin is damaged (Zuefle and Loeb 2014), imported tomatoes are not considered in the potential pathway analysis as Australia currently only imports tomatoes from New Zealand, which is free of SWD (Hort Innovation 2019).

Origin countries

Regarding import origins of primary concern, since 2008, SWD has rapidly expanded its international range to a large number of exporting countries, which notably includes the United States, Europe (most countries), China, Brazil, Argentina, Canada, Japan, Korea, Myanmar, India, and Thailand. While the general pathway in terms of origin countries has been inferred from genetic analysis (Section 3.1.1), there does not yet appear to be further details on the pathways of spread into the United States mainland or Europe (i.e. the specific regulated or unregulated pathways).

For exporting countries where SWD occurs, table grapes, oranges, and kiwifruit constitute commodities imported in the largest volume (

Figure 13). Fruit from Italy and the United States are significant in terms of volume but the low suitability of citrus as hosts should be noted (Figure 17). In addition, growing regions of the Netherlands (fresh flowers) and France (fresh flowers, caneberries, and kiwifruit) were identified as possessing highly suitable ecoclimatic conditions for the pest, despite lower import volumes.

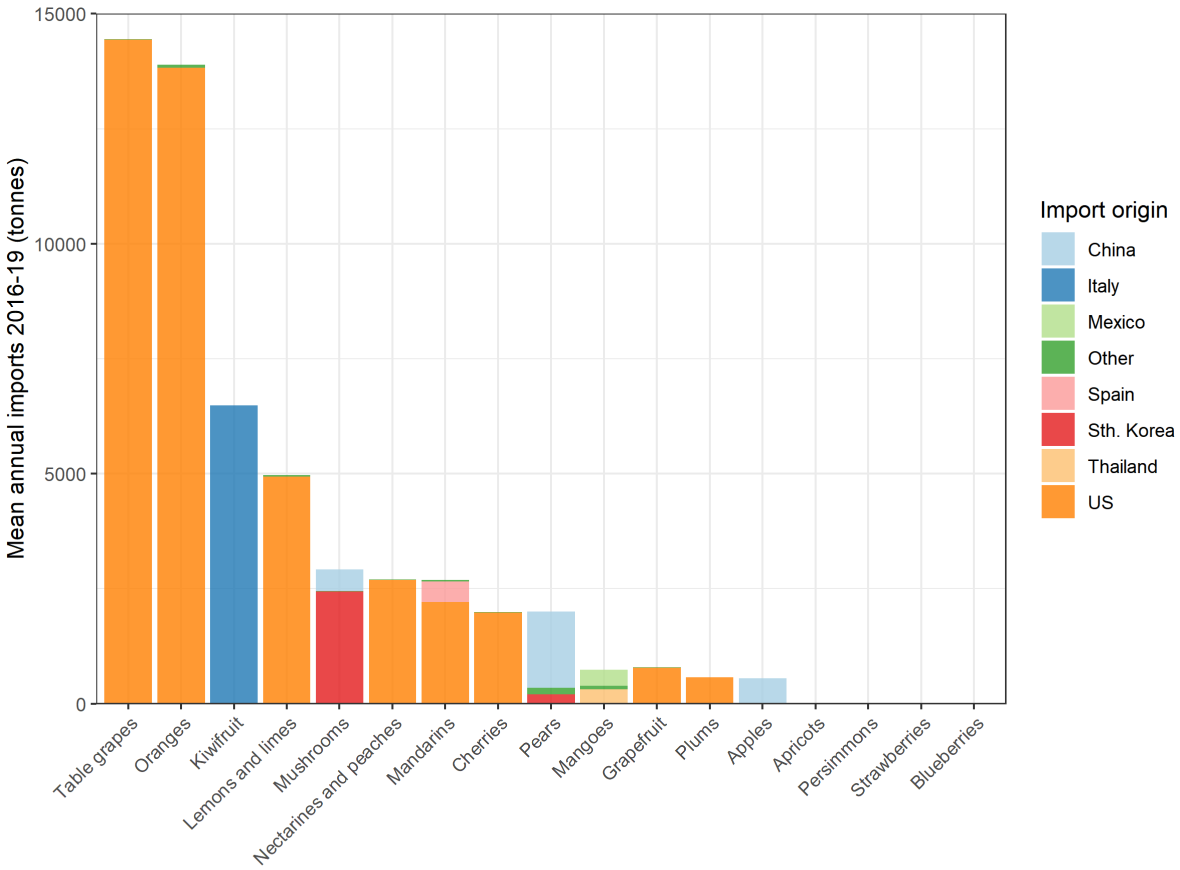


Figure 13: Annual Australian imports of fruits associated with SWD from countries in which SWD is known to occur averaged over years 2016-2019. Data sourced from the Australian Horticultural Statistics handbook (HIA 2019)

State based pathways

Different Australian states are likely to have different risks of importation of SWD due to different import volumes of potential hosts (Figure 14). In the absence of country-of-origin for state-level import data, import volumes shown represent all imports (from countries where SWD is absent or present). Nevertheless, the state-level import profile identifies that Victoria and New South Wales are most at risk of importing SWD with respect to their import profile. South Australia was associated with the lowest import volumes of all importing states. These import profiles broadly correspond with state population sizes, and thus demand for fresh produce. The import profile for each Australian state did not vary substantially in terms of the composition of imports.

While import risks may be lower in Queensland (based on import volumes), other ecological and socio-economic factors of populated regions, such as Brisbane, will increase the establishment, spread, and incursion potential, which may nevertheless result in the prioritisation of monitoring at other ports of entry.

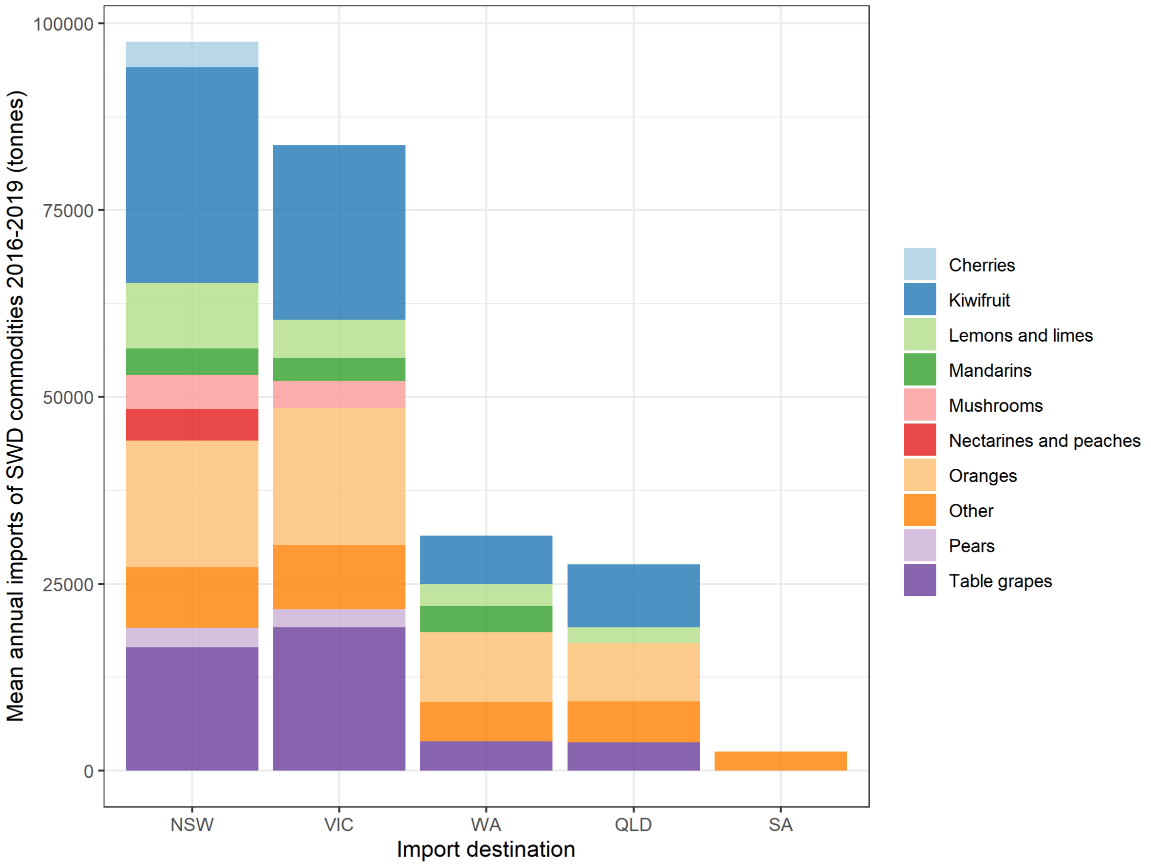


Figure 14. Quantity of SWD associated commodities (both primary and secondary) imported by Australian states averaged across over years 2016 – 2018 from countries both with and without SWD. Data sourced from the Australian Horticultural Statistics Handbook (HIA 2019). If imports for a state are less than 2000 tonne, they are classed as "other".

Temporal trends

Annual trends across 9 years of Australian import volumes (Figure 15) of commodities associated with SWD highlighted increasing import volumes for several commodities (e.g. plums, fresh flowers, grapes and blueberries), with strawberry imports decreasing substantially. Since 2011, imports of strawberries have declined from approximately 150 tonnes to 1 tonne.

Imported commodities compensate for shortfalls in domestic supply. Thus, import seasonality of commodities generally reflects periods of low domestic supply. This includes during socioeconomic factors or events that may disrupt supply such as climatic events which may increase import demands resulting in an increase risk. For imported commodities associated with SWD (Figure 16), there is a large winter increase in imported cherries, table grapes, peaches, nectarines and plums (predominantly from the United States). Conversely, there are large summer increases in imports of citrus (predominantly from the United States) and kiwifruit (predominantly from Italy). Other commodities exhibit relatively stable patterns in seasonality (e.g. fresh flowers) or are erratic due to low import volumes (e.g. strawberries). Given the large proportion of Australian imports, volumes from New Zealand (e.g. kiwifruit and blueberries) and Kenya (e.g. fresh flowers) are indicated in the seasonality plot despite SWD not known to occur in these regions (Figure 16).

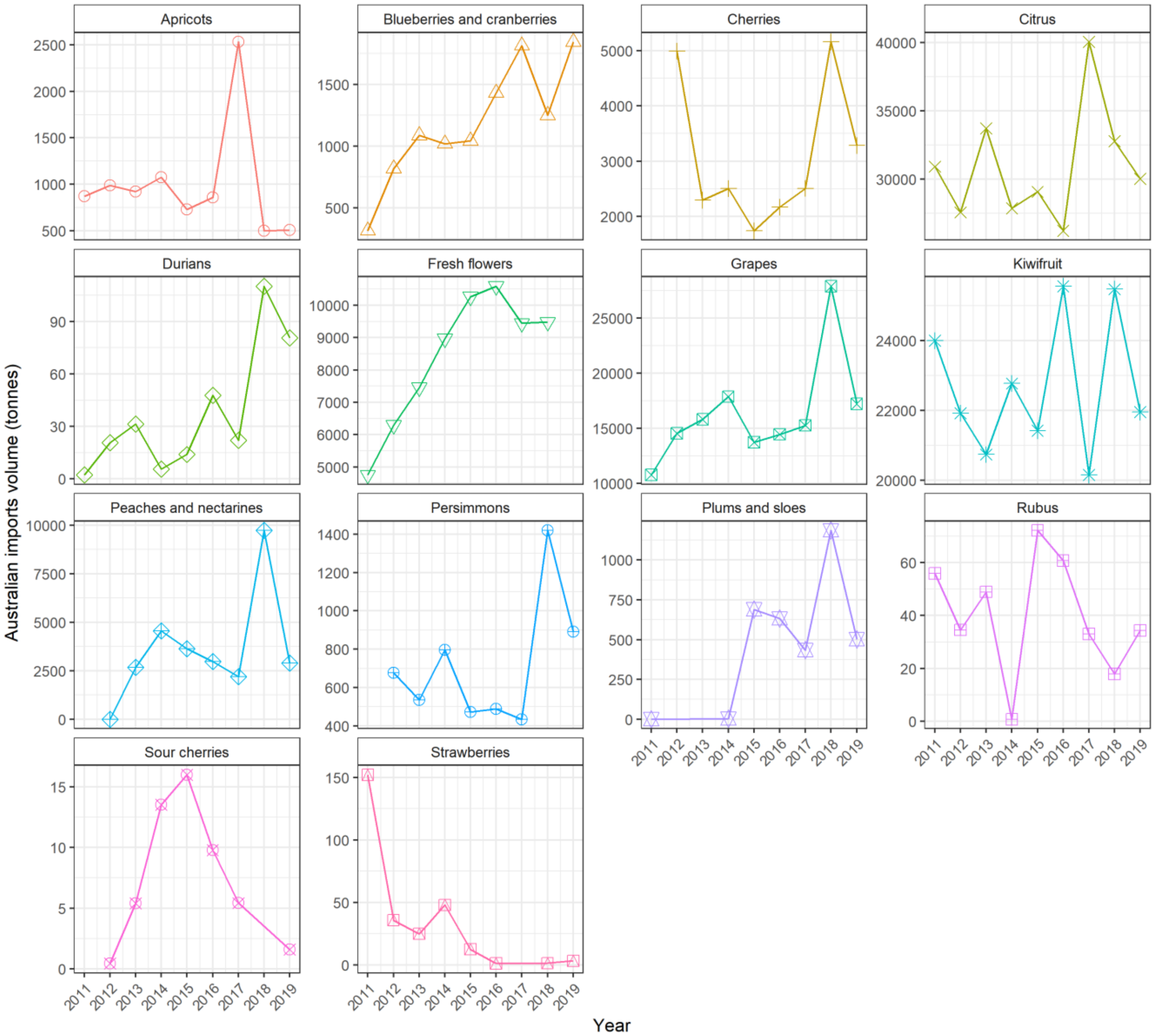


Figure 15. Volume of Australian imports of primary and secondary host commodities associated with spotted wing drosophila. Data is compiled from the UN Comtrade database (Comtrade 2015).

Figure 16: Annual mean seasonality of imports of SWD associated commodities were significant origin countries are indicated. SWD are not presently known to occur in New Zealand and Kenya but are shown due to their strong contribution to particular commodity imports. Data is compiled from the UN Comtrade database (Comtrade 2015).

Overall pathway risk analysis

The quantitative risk analysis conducted by **cesar** identified the potential pathways by combining differences in commodity suitability (host import risk) and ecological suitability (mean estimated population growth potential) at the import origin are incorporated with Comtrade data (

Figure 17). This analysis again identifies that fruit from Italy and the United States are significant in terms of volume (noting the low suitability of citrus as hosts). In addition, growing regions of the Netherlands (fresh flowers) and France (fresh flowers, *Rubus*, and kiwifruit) were identified as possessing highly suitable ecoclimatic conditions for the pest, despite lower import volumes.

The high winter seasonality of many Australian imports of fruit, as well as more favourable conditions for SWD of winter in south-eastern regions, suggests that incursions through regulated trade pathways may be most likely during the winter period in south-eastern states. Notably, table grapes from the United States were identified as posing risks of SWD importation due to the very high volume of imports, high-suitability of production regions in the United States, and medium host-risk ascribed to grapes as a host. The high volume of imported grapes into Australia during winter (when conditions are favourable for SWD in the major importing states of Victoria and New South Wales) also contributes to this risk. Australian import requirements of table grapes from the United States are highly stringent and include phytosanitary measures at both import source and destination to mitigate these risk factors. However, with other significant hosts, such as cherries, peaches, nectarines, plums also imported at their highest volumes during winter, surveillance may increase the probability of early detection by prioritising Victorian or New South Wales ports of entry during the winter-spring period.

Citrus fruit from the United States are also imported at large volumes into Australia but are likely to be lower risk due to citrus fruits lower suitability as a host (with only damaged fruit viable for SWD development), and the seasonality of imports, which occur predominantly in summer when high temperature and moisture stress are likely to decrease SWD establishment risk. Despite these mitigating factors, SWD was detected in a consignment of fresh oranges that likely included damaged fruit during import into New Zealand from the United States (DAWR 2019). This demonstrates that this high-volume pathway may nevertheless pose some risk.

Considering the pathway analysis presented above some broad priorities for surveillance of fruit to support the early detection of SWD on the basis of trade volumes, the international distribution of SWD, and ecoclimatic suitability can be made.

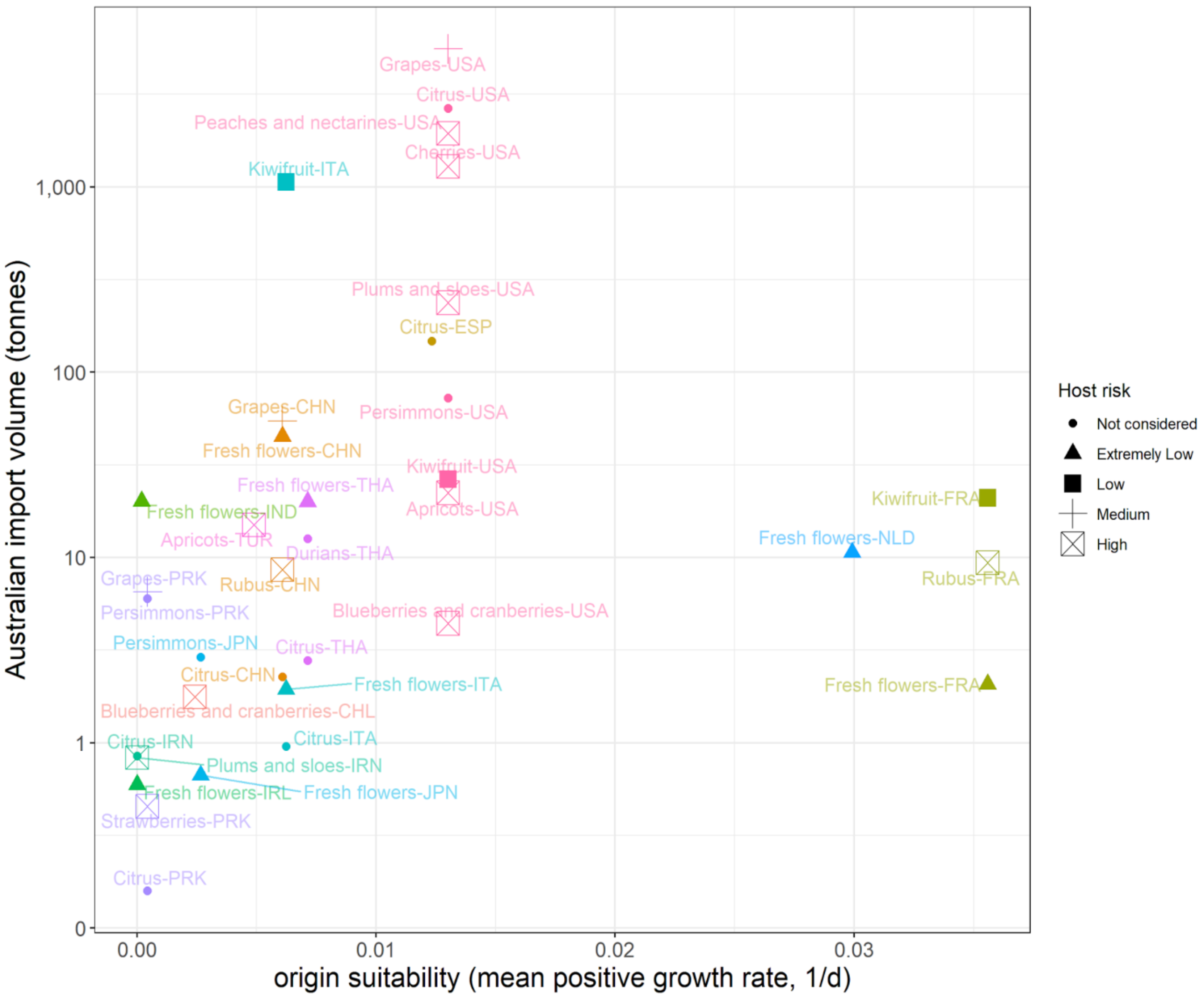


Figure 17: The total Australian import volume, environmental suitability at import-origin, and host-affiliation of SWD pathways. Trade volume data is compiled from UN Comtrade and averaged over 2008-2019. Host-risk is the host-specific importation risk as assigned in the Pest Risk Analysis (Department of Agriculture Fisheries and Forestry Biosecurity 2013). The import-origin suitability is the mean annual SWD population growth rate estimated across production areas for each country using suitability layer generated in Maino (2020a). Country codes are given as follows: CHE: Switzerland; CHL: Chile; CHN: China; ESP: Spain; FRA: France; IND: India; IRL: Ireland; IRN: Iran; ITA: Italy; JPN: Japan; NLD: Netherlands; PAK: Pakistan; PRK: North Korea; THA: Thailand; TUR: Turkey; USA: United States of America.

3.1.2.2 Soil

Soil can also be a potential pathway. Pupation in the in the soil under host plants is likely. Therefore, soil can be a potential pathway for SWD spread. This risk can be minimised by only transferring bare rooted plants for planting from infested areas. Further details relating to this risk pathway are included in pest risk analysis report for *Drosophila suzukii* (DAFF 2013).

3.1.2.3 Cut flowers

Cut flowers present a low risk. The species considered as potential hosts as cut flowers are *Styrax japonicus* and *Camelia japonica*. However, these species are not recorded as cut flowers in the booklet of the Flower Council of Holland which contains 756 cut flowers in demand (Flower Council of Holland, 2009). Furthermore, it is reported that flowers are only known to be attacked by SWD in the absence of host fruits with attack in spring, after adults emerge from winter diapause and before fruits ripen in late spring (Mitsui et al. 2010).

3.1.2.4 Hitchhiking

Larvae usually remain in the fruit. Commercially grown fruits that are traded are likely to be free from symptoms of attack (so mainly infected with young larvae that will not leave the fruit). However, the risk of hitchhiking cannot be completely ruled out that some larvae (the most mature) leave the infested fruit during the transportation and wander on the crates to search for a place to pupate. Though, the high humidity requirements for survival during the pupation stage makes that this is a very unlikely pathway.

Similarly, adults may be able to survive low temperatures during transport and enter into a winter diapause allowing hitchhiking spread. It has been shown that at temperatures above 5 °C, adult cold mortality became minor even after prolonged exposures (e.g., only 20% mortality after one month at 7.5 °C) (Enriquez and Colinet 2017). The immature stages (eggs, larvae and pupae) of SWD are less cold tolerant than adults. The immature stages of SWD were all dead after a 6-d cold treatment at 1°C and 8-d cold treatment at 1.5 and 2°C in grapes (Kim et al. 2018). However, this risk of this occurring is considered to be medium to low depending on cold storage treatments applied during transport and SWD life stage.

3.2 Establishment potential

Independent studies modelling the potential global distribution of SWD have concluded that there are substantial regions of Australia with high climatic suitability (dos Santos et al. 2017, Ørsted and Ørsted 2019) Building upon these studies **cesar** has developed a model of establishment potential of SWD in Australia. The full report can be found at https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/A large portion of Australia's southern and eastern coastal fringe, as well as some restricted areas in western Australia were predicted to have climates that will support SWD populations (Figure 18).

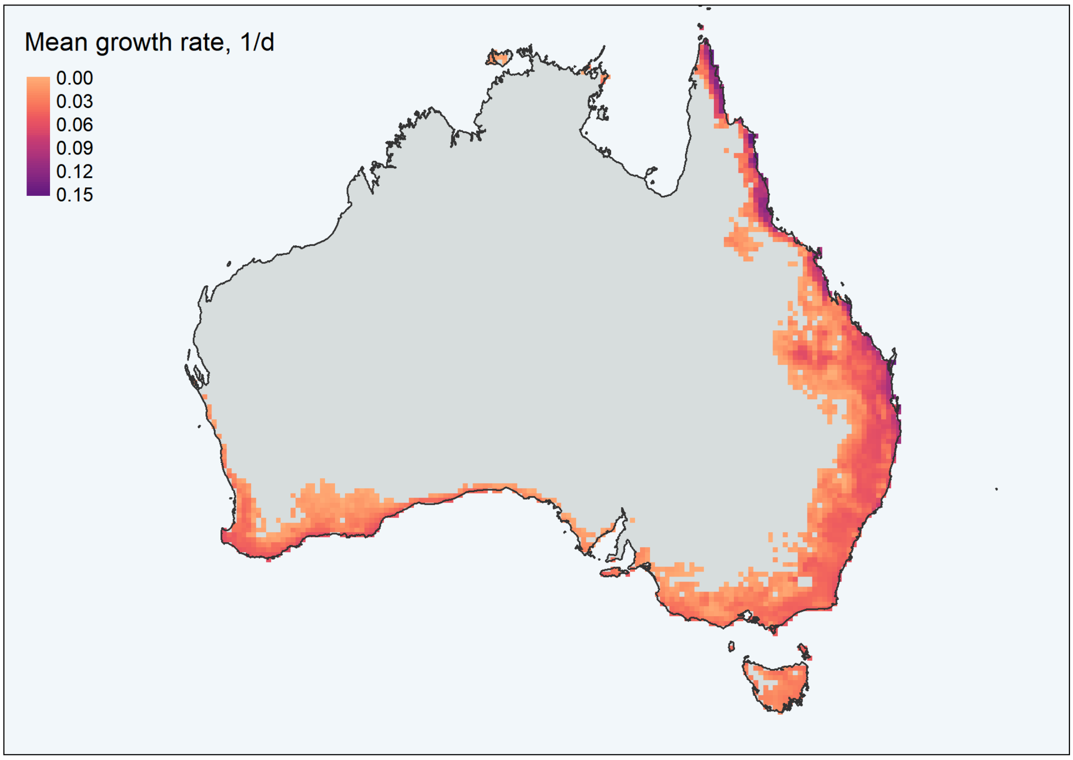


Figure 18: Modelled mean annual intrinsic population growth rate of SWD in Australia.

Model validation

Using biological parameters measured in laboratory studies, the resulting climate-based population growth model successfully captured the global distribution of SWD, which provides confidence when projecting to novel ranges, such as Australia (Figure 19).

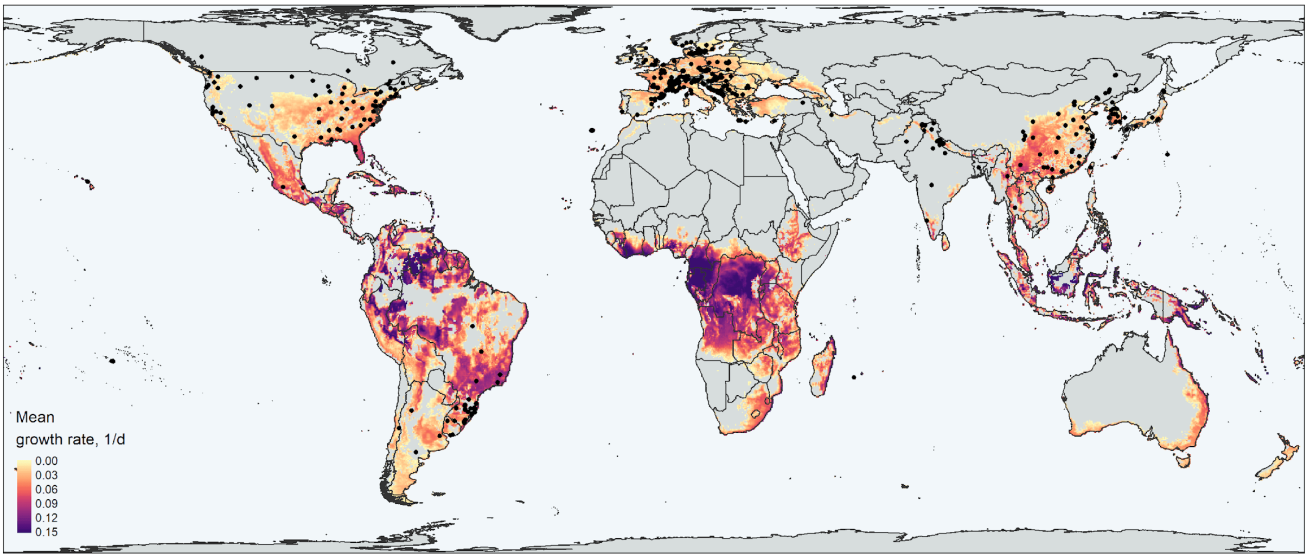


Figure 19 Modelled mean annual intrinsic population growth rate of SWD plotted against the current distribution (black circles) (Ørsted and Ørsted 2019).

3.3 Spread potential

One of the most alarming attributes of SWD is its ability to invade a region quickly. This is due to a range of factors including its cryptic nature, (very small eggs and larvae and similarity to non-damaging *Drosophila* spp.), high reproductive rates, relatively long life, broad host range, and capacity to survive in both cool and warm areas (Emiljanowicz et al. 2014). In Japan (on cherries), SWD has been shown to undergo 13 generations/yr (Kanzawa 1939). Oviposition rates for SWD can exceed 25 eggs/day/female, depending on temperature (Kinjo et al. 2014).

The spread across the European continent has been rapid and parallels what was observed in North America (Burrack et al. 2012). Lengyel et al. (2015) estimated spread to be around 320–390 km year, while Calabria et al. (2012) estimated that SWD was able to spread approximately 1,400 km a year.

The relatively high spread rate of SWD supports the concept of vehicles as a key means of transport for medium-distance movement within continents and countries. The Hungarian example suggests that transport along highways could have been a key means of spread for SWD. Traps at highway rest areas were positive for SWD from the survey outset, while many other traps around the country remained negative. In addition, there were no orchards near the detection site, supporting the hypothesis that the flies arrived by transport along the highway rather than making their own way from surrounding habitat (Lengyel et al. 2015). This does not preclude other means of human-mediated spread, for example transport by air, rail or sea, nor does it rule out natural spread, with the flies gradually expanding their geographic range in a country or continent without human intervention (i.e. by adult flight or being blown by the wind).

cesar modelled the ecoclimatic and anthropogenic drivers of SWD establishment and spread to improve forecasts of incursion scenarios into Australia. Simulation results showed that despite variation in human population densities and climatic suitability between tested incursion scenarios, SWD was predicted to rapidly fill its climatic niche in Australia with only minor variation in likely spread pathways across 50 replicated 6-year incursion simulations, highlighting the rapid spread potential of SWD in Australia in the event of an incursion. At shorter timescales, incursion location had a large impact on spread potential which has been made available through an interactive map (https://cesaraustralia.shinyapps.io/SWDportal/) with preloaded spread simulations and the ability to overlay production value of key commodities (screenshots in Figure 20). Nevertheless, the high spread potential of SWD will make post-incursion eradication programs extremely difficult and expensive, suggesting that border-security and quarantine procedures will be a crucial preventative measure.

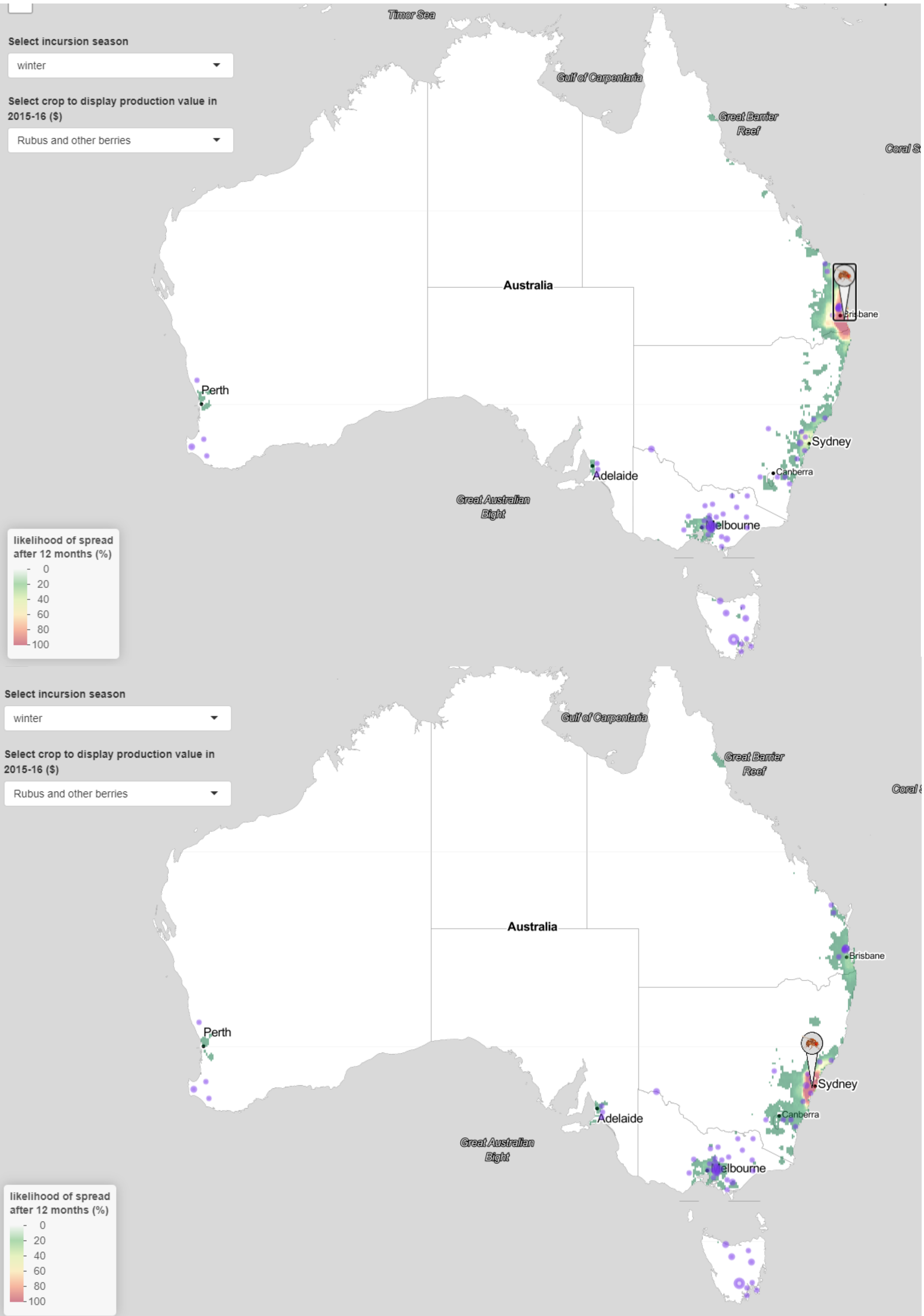


Figure 20: The strength of spread pathways where the color of each grid cell indicates the proportion of 100 replicated simulations in which SWD was present across 12 months following an incursion originating at the marker on Brisbane and Sydney. The spread represents unmitigated spread. Interactive map available at (https://cesaraustralia.shinyapps.io/SWDportal/)

A simplifying assumption of the model is that SWD is unlikely to be limited by a lack of wild non-crop hosts. In Australia, this assumption is defensible on basis of the wide distribution of some key wild non-crop hosts. For example, the wide distribution of *Rubus* species (Figure 21) demonstrates a wide overlap with the predicted range of environments climatically suitable for SWD in Australia. While these *Rubus* records include highly suitable and widespread host species such as wild blackberry, *Rubus occidentalis*, SWD will be able to utilise other less suitable non-crop hosts, such as some species belonging to *Prunus,* particularly, with wild hosts prone to damage (e.g. from birds) or becoming overripe, which will both increase the suitability for SWD oviposition and larval development.

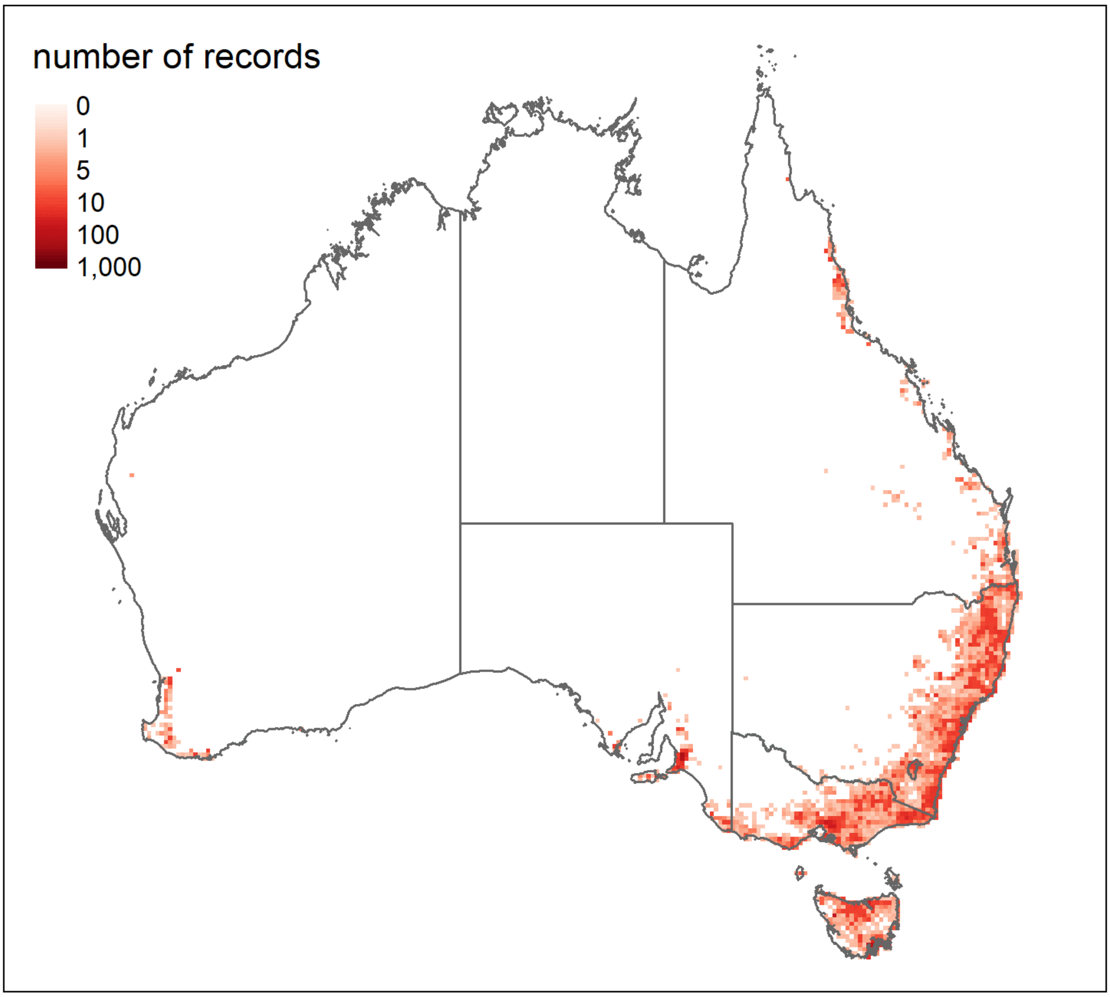


Figure 21: Spatial distribution of Rubus sp. reported in the Australian Living Atlas database suggest that the distribution of non-crop hosts is unlikely to be limiting factor in the spread of SWD.

3.4 Economic impact

3.4.1 Worldwide

Worldwide, the economic impacts of this pest for horticultural industries have been significant. As SWD larvae develop inside the fruit they feed on the flesh, resulting in soft, sunken and discoloured areas (Walsh et al. 2011, Mazzi et al. 2017). The oviposition wound creates an opportunity for other insect pests and for entry of fungal or bacterial pathogens. Thus, damage occurs through direct yield loss and reduced marketability of fruit with no practical option for treating infested commodities or redirecting them to alternative markets. The flow on detrimental impacts from SWD can take many forms, including management costs, post-harvest sorting costs, and market access implications.

cesar has conducted an international literature review ((Maino 2020a) on the impacts of SWD worldwide. The review resulted in 244 reports on 16 commodities (Table 8), where the top 6 most reported commodities in descending order were blueberries, raspberries, blackberries, strawberries, table grapes, and sweet cherries. The number of reports did not necessarily correspond with the level of reported crop loss (Table 8). The most vulnerable fruits (mean reported crop losses) included raspberries (31%), blackberries (24%), cherries (17%), blueberries (14%), strawberries (8%) and table grapes (7%). Notably, there was large variation in the estimated rate of impacts, both within and between commodities. For example, infested raspberries exhibited a mean reported crop loss 31% which was higher than strawberries at 8%, but also exhibited more variation with a reported range of 0-100% and 0-80% respectively.

After compiling international reports of crop losses, most variation in impacts was associated with commodity type and years since establishment. The regression of crop losses (Figure 22) confirmed that commodity type explained most of the variance of all explanatory factors tested (15%), followed by years since SWD established in region (13%), and finally latitude (8%). Mean impacts were estimated to vary from 15-50% in the first 2 years following establishment but decreased to under 10% after 6 years. The association with commodity type is likely to reflect intrinsic factors such as permeability of fruit skin (Stewart et al. 2014) or frost susceptibility, while the negative association with years since likely reflects changes in cultural practices, such as harvest schedules, and chemical and biological control strategies in response to the new pest. This finding will help justify a quick transition to best practice management practices to avoid the initial high losses following establishment.

Table 8. Impact potential of SWD on affected commodities in terms of international collated reports of proportions crop value lost due to feeding damage. The table is ordered by the number of total crop loss reports. Australia's total production value of each commodity is provided.

Plant name	Common name	Value* ($ mil.)	Proportion reported Crop Loss			N	Sources
			Mean	Min	Max		
Vaccinium	Blueberries	$193.60	0.14	0	1	56	eFly working group, 2014; eFly working group, 2012; eFly working group, 2015; Bolda et al. 2010; Cowles 2011; De Ros et al. 2015; del Fava et al. 2017; Grassi et al. 2011
Rubus	Raspberries	$141.53	0.31	0	1	52	(eFly working group, 2012; eFly working group, 2015; Bolda et al. 2010; Farnsworth et al. 2017; eFly working group, 2014; Cowles 2011; Sward et al. 2016; De Ros et al. 2015; del Fava et al. 2018; Grassi et al. 2011
Rubus	Blackberries	$23.31	0.24	0	1	45	(eFly working group, 2014), (eFly working group, 2012), (eFly working group, 2015), (Bolda et al. 2010), (De Ros et al. 2015), (del Fava et al. 2017), (Grassi et al. 2011)
Fragaria	Strawberries	$506.50	0.08	0	0.8	45	eFly working group, 2014; eFly working group, 2015; Bolda et al.

Plant name	Common name	Value* ($ mil.)	Proportion reported Crop Loss			N	Sources
			Mean	Min	Max		
							2010; eFly working group, 2012; De Ros et al. 2015; del Fava et al. 2017; Grassi et al. 2011
Vitis	Table grapes	$534.40	0.07	0	0.35	23	eFly working group, 2014; eFly working group, 2015; eFly working group, 2012; Cowles 2011
Prunus avium	Sweet cherries	$120.70	0.17	0	0.9	17	Bolda et al. 2010; eFly working group, 2012; eFly working group, 2014; eFly working group, 2015, Grassi et al. 2011
Psidium cattleianum	Guava	NA	0.74	0.74	0.74	1	Lasa et al. 2017
Prunus armeniaca	Apricot	$29.90	0.35	0.35	0.35	1	Grassi et al. 2011
Prunus domestica	Plum	$74.80	0.20	0.2	0.2	1	Escudero et al. 2011
Prunus persica	Peach	$112.56	0.10	0.1	0.1	1	eFly working group, 2012
Prunus persica var. Nucipersica	Nectarine	$168.84	0.10	0.1	0.1	1	eFly working group, 2012
Diospyros kaki	Persimmon	$10.50	0.01	0.01	0.01	1	Kanzawa, 1939
Actinidia	Kiwi	$20.40	0	0	0	1	MPI, 2012
Malus domestica	Apple	$441.50	0	0	0	1	DAFF, 2013
Ribes	Currants	$27.00	0	0	0	1	Grassi et al. 2011
Vitis	Wine grapes	NA	0	0	0	1	eFly working group, 2012

* Horticultural Statistics Handbook 2016-17

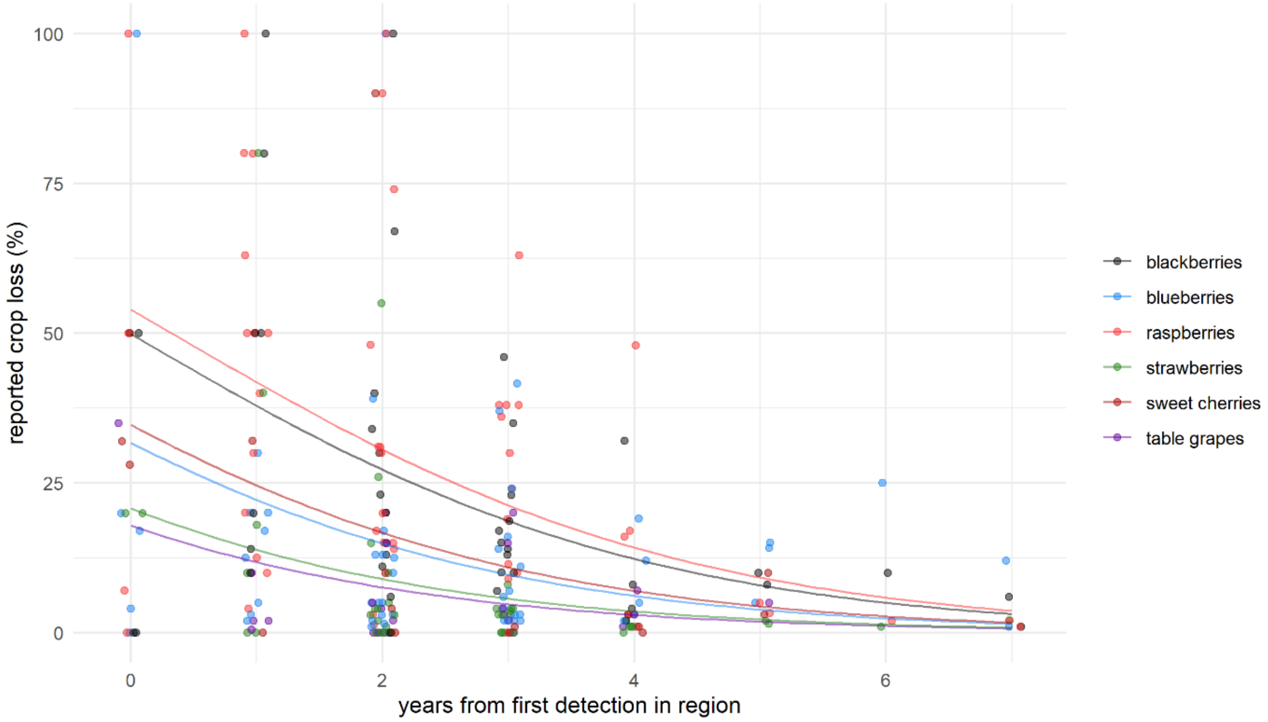


Figure 22: Negative relationship with reported crop loss and years from first detection in region demonstrating the effect of adapting management practices. Controlling for commodity effects (unique intercepts), the odds of any fruit being infested by SWD decrease by 39% for each year following initial outbreaks. Overall predictability is nevertheless poor with ~15% explained by time and ~16% of deviance explained by commodity type. Only 8% of variation was explained by latitude.

3.4.2 Predicted impact in Australia

Fruit industries, locally valued at $4.8 billion, remain highly vulnerable to an incursion of SWD (Hort Innovation 2019). In descending order, the largest industries of vulnerable commodities were table grapes ($408.3 mil.), strawberries ($265.1 mil.), cherries ($150.3 mil.), blueberries ($144.3 mil.), nectarines ($71.6 mil.), peaches ($57.5 mil.), plums ($38.9 mil.), rubus and other berries ($31.1 mil.), and apricots ($20.2 mil.). In descending order, most affected commodities were produced in Victoria ($586.1 mil.), New South Wales ($202.2 mil.), Queensland ($201.9 mil.), Tasmania ($107.3 mil.), Western Australia ($72.4 mil.), South Australia ($65.1 mil.), and the Northern Territory ($1.3 mil.) (Figure 23: Distribution of the values of key affected commodity production in Australia based on ABS agricultural census data collected for 2015-16.Figure 23).

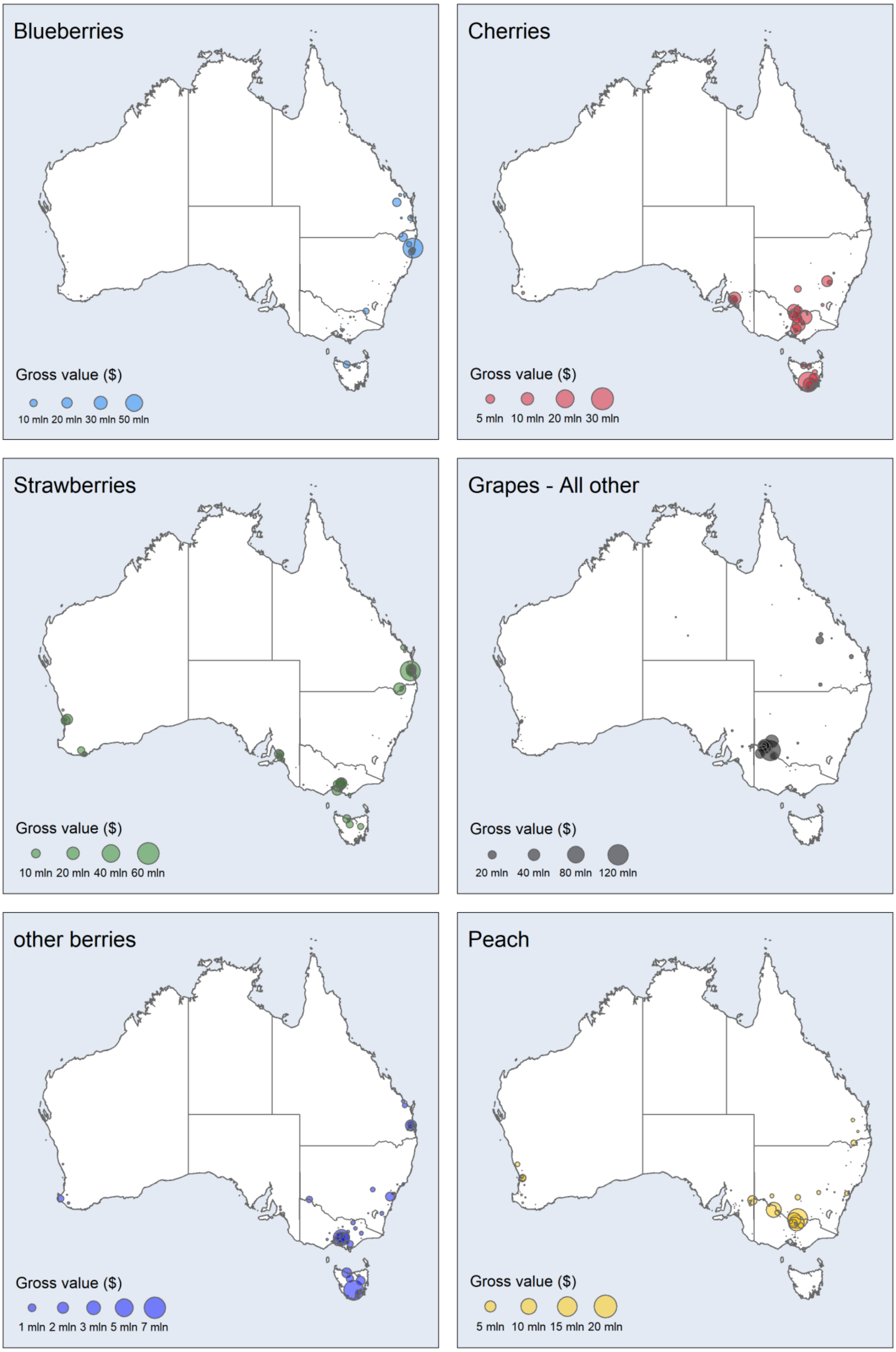


Figure 23: Distribution of the values of key affected commodity production in Australia based on ABS agricultural census data collected for 2015-16.

Considered at a value per state, Victoria and New South Wales are evidently the states that would be m0ost impacted by uncontrolled populations of SWD in respect to the total value of production. However, this potential impact needs to be considered against the local climatic suitability and relative impacts to different crops. As a result, individual states might be more or less impacted as a proportion of their respective horticultural production.

To incorporate environmental conditions into estimates of economic impacts of SWD to Australian horticulture, a spatially explicit simulation framework by **cesar** was developed (Maino 2020a). The framework includes modules for population establishment, growth, and spread, which are overlaid onto the spatial distribution of susceptible horticultural productivity to estimate impacts through time. Unmitigated impacts were defined as the direct cost in terms of lost production associated with the predicted spread and establishment of SWD without mitigation (e.g. implementation of surveillance, quarantine, or management programs for SWD). To explore the different incursion scenarios, initial outbreaks were simulated (and followed across three years) in capital cities Melbourne, Adelaide, Hobart, Brisbane, Sydney and Perth, which represents a range of different climates, human population densities and surrounding production industries. To focus on the role of spatial variation in crop production and temporal environmental suitability, crop losses were assumed to be 10% of production value. The fixed value of ten percent was taken as a reasonable estimate across different commodities under management (acknowledging bias towards the reporting of high losses as minor losses may go unnoticed or unreported), and to simplify the wide variation that has been observed even within commodities. To adjust this assumption, impact estimates can be easily scaled (e.g. multiply estimated impacts by two if assumption is 20% crop loss).

Predicted impacts the first three years following incursions were substantial across all incursion scenarios (Figure 23Figure 24). Variation in accumulated impacts could be seen across incursion locations and commodities, which ranged from $16.6 – 61.3 million (Figure 23Figure 24). Pooling all affected commodities, Brisbane was predicted to see the fastest accumulating and total national impacts due to its climatic suitability, large affected industries, and proximity to other large populations facilitating spread. Incursions into Sydney saw the next most rapid initial accumulation of impacts but was then overtaken by the Hobart incursion simulation over time.

The effect of incursion location depended on the commodity considered. For example, national cherry production was most vulnerable to a Tasmanian incursion. While national nectarines, plums, and peach production was most vulnerable to a Perth incursion (Figure 23Figure 24). Impacts did not necessarily correspond to the size of the industry with impacts to strawberries predicted to see higher impacts than table grapes despite their smaller contribution to total soft fruit production (Table 9). Indeed, at the jurisdiction level, Queensland saw the largest impacts at $33.28 million after 3 years accounted for mostly by strawberry and blueberry production. Interestingly, significant table grape production in the Sunraysia region in north-western Victoria, was not predicted to be impacted within three years of any of the incursions from capital cities.

Within jurisdictions, incursions at capital cities led to the greatest impacts in all cases, compared to other local incursions (Table 9). The closest exception to this was Devonport, which saw nearly as large an impact for Tasmanian soft fruit industries ($12.88 million) compared with Hobart ($13.10 million).

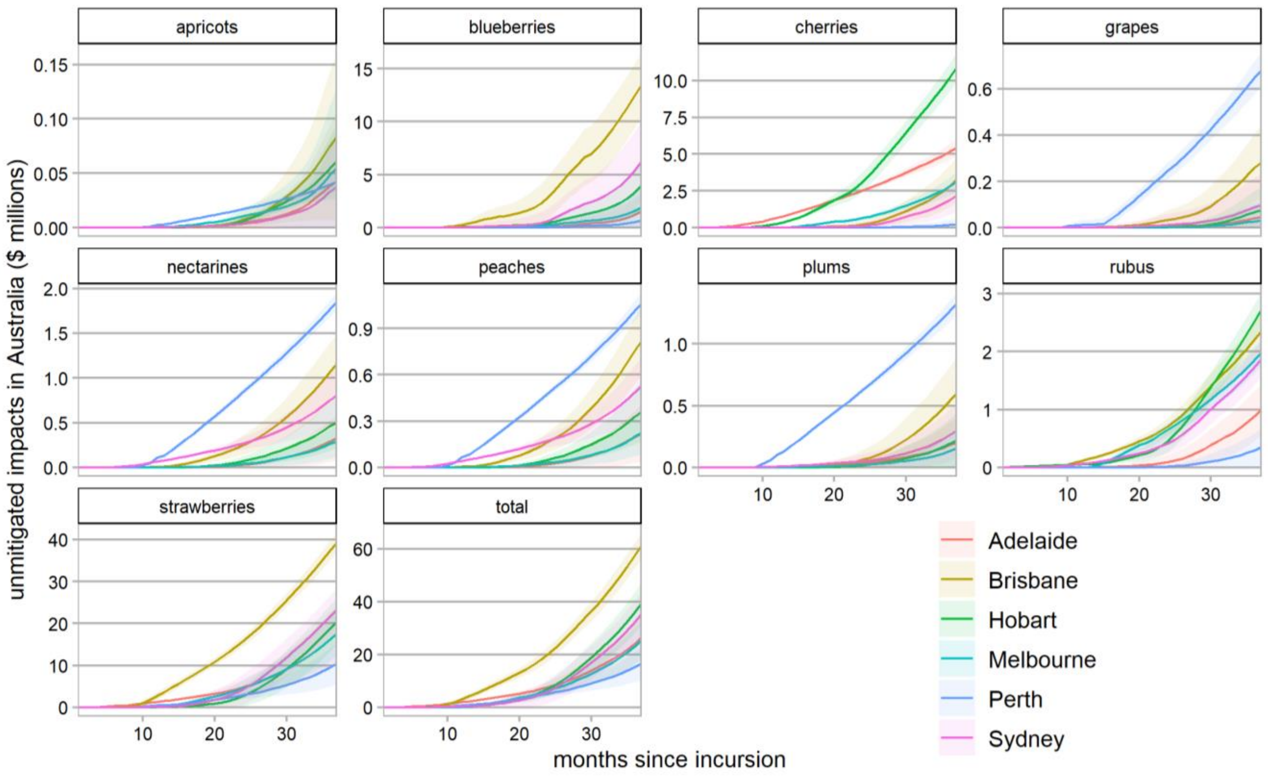


Figure 24: Accumulated national impacts through time dependent on incursion and commodity production location. A developed spread model for SWD (Maino 2020) which was able to account for: environmental conditions on SWD population growth, short-ranged dispersal, and human assisted dispersal was extended to calculated impacts through time following different incursion scenarios. Incursion scenarios were conducted for key locations to explore the impact of incursion location to total estimated impacts. Simulations were replicated 100 times with means (solid line) and standard deviations (faded areas bounding means) shown. Note that due to the large variation in impacts both between and within crop the proportion crop impact was fixed at 10% in order to explore variability due to incursion location and the size and distribution of different soft-fruit production industries. Thus, the plotted standard deviation reflects uncertainty in dispersal processes rather than damage.

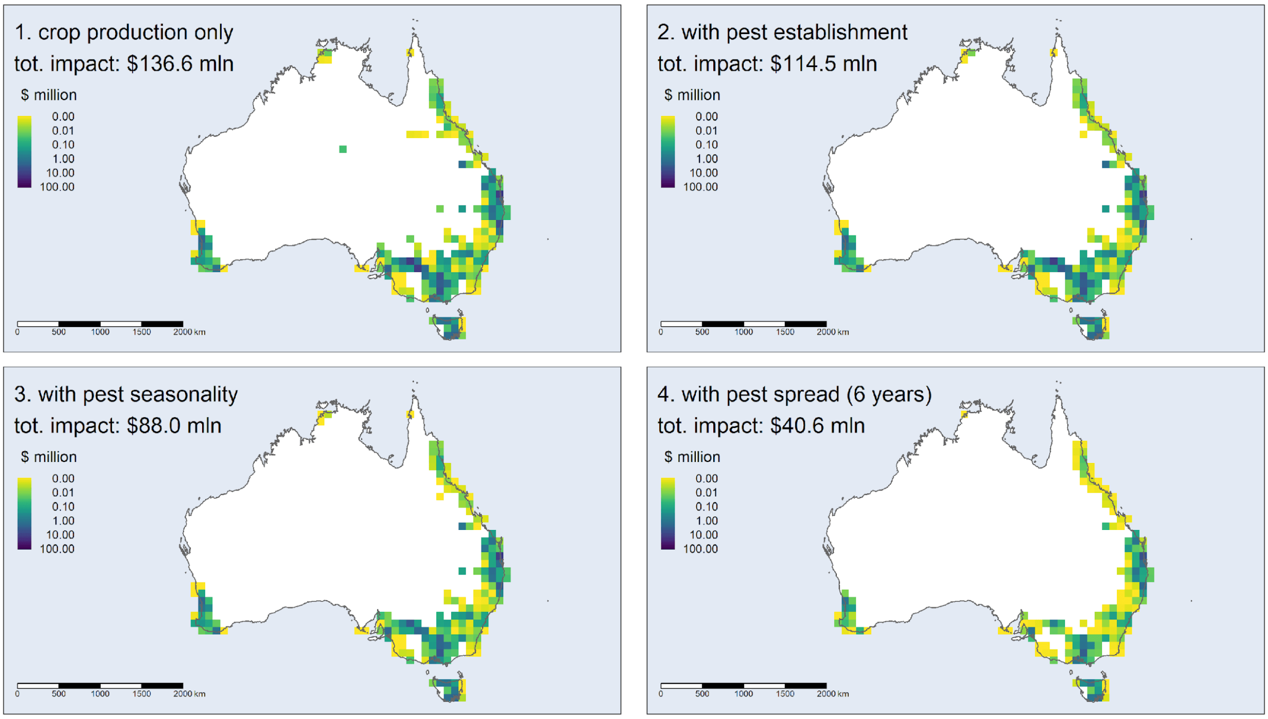


Figure 25. Annual pest impacts are can be estimated with incremental model complexity and differ based on whether impacts: 1) are assumed to be a simple proportion (10%) of gross production of susceptible commodities (top left), 2) are also restricted by climatic conditions that support population growth (top right), 3) are also scaled by the proportion of the year over which the pest is active (bottom left), and 4) are scaled by the mean predicted years established following a Melbourne incursion with impacts averaged over 6 years (bottom right).

Table 9. Accumulated impacts in dollars (millions) at 3 years following SWD establishment within each state jurisdiction, for each local incursion scenario, and commodity category. Simulations were replicated 100 times with means and standard deviations shown. Due to the large variation in impacts both between and within crop the proportion crop impact was fixed at 10% in order to isolate variability caused by incursion location and the size and distribution of different soft-fruit production industries.

STATE	INCURSION	APRICOTS	BLUEBERRIES	CHERRIES	GRAPES	NECTARINES	PEACHES	PLUMS	CANEBERRIES	STRAWBERRIES	TOTAL
NSW	Coffs Harbour	0.00 (0.00)	3.41 (3.77)	0.03 (0.11)	0.00 (0.00)	0.26 (0.14)	0.16 (0.09)	0.04 (0.02)	0.18 (0.11)	0.09 (0.05)	4.18 (3.93)
NSW	Sydney	0.00 (0.00)	4.68 (3.54)	0.14 (0.22)	0.00 (0.00)	0.50 (0.02)	0.32 (0.01)	0.08 (0.00)	0.41 (0.02)	0.23 (0.01)	6.36 (3.58)
QLD	Brisbane	0.03 (0.02)	2.23 (0.20)	0.00 (0.00)	0.09 (0.07)	0.22 (0.07)	0.24 (0.07)	0.13 (0.07)	1.00 (0.04)	29.33 (1.31)	33.28 (1.60)
QLD	Cairns	0.02 (0.01)	1.88 (0.22)	0.00 (0.00)	0.14 (0.04)	0.12 (0.05)	0.13 (0.06)	0.06 (0.05)	0.83 (0.10)	23.86 (2.99)	27.04 (3.32)
SA	Adelaide	0.02 (0.00)	0.01 (0.00)	4.61 (0.01)	0.01 (0.00)	0.00 (0.00)	0.01 (0.00)	0.06 (0.00)	0.04 (0.00)	6.52 (0.09)	11.28 (0.11)
SA	Port Augusta	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Tas	Devonport	0.01 (0.01)	2.67 (0.10)	4.01 (1.60)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)	1.08 (0.29)	5.09 (0.33)	12.88 (2.03)
Tas	Hobart	0.03 (0.01)	0.97 (0.48)	9.30 (0.68)	0.00 (0.00)	0.01 (0.00)	0.03 (0.00)	0.00 (0.00)	1.23 (0.21)	1.53 (0.72)	13.10 (1.56)
Vic	Melbourne	0.05 (0.07)	0.51 (0.04)	2.71 (0.42)	0.00 (0.00)	0.04 (0.03)	0.07 (0.09)	0.09 (0.11)	1.57 (0.10)	10.36 (0.63)	15.40 (1.02)
Vic	Mildura	0.00 (0.01)	0.06 (0.13)	0.26 (0.54)	2.87 (0.00)	0.00 (0.01)	0.00 (0.01)	0.01 (0.01)	0.20 (0.39)	1.37 (2.57)	4.77 (3.62)
WA	Geraldton	0.02 (0.01)	0.05 (0.03)	0.01 (0.01)	0.30 (0.14)	0.87 (0.30)	0.49 (0.17)	0.62 (0.22)	0.01 (0.03)	2.80 (1.39)	5.16 (1.82)
WA	Perth	0.04 (0.00)	0.11 (0.02)	0.02 (0.02)	0.68 (0.07)	1.76 (0.05)	1.00 (0.02)	1.31 (0.09)	0.04 (0.04)	5.97 (0.31)	10.92 (0.39)

4 SURVEILLANCE AND COLLECTION OF SAMPLES

4.1 Surveillance tools

Current surveillance methods targeting adult female and male SWD use a trap-and lure system that uses visual and olfactory cues of *Drosophila*. Surveillance methods targeting larvae consist of fruit checks and extraction of larvae. The following sections will outline current knowledge and commercially available surveillance options for SWD.

4.1.1 Surveillance for Adults

Adult SWD flies use colours (Menne and Spatz 1977) and fruit volatiles to find their hosts (Lebreton et al. 2012). As such, surveillance for adult SWD has typically been conducted with lures and traps. Historically, SWD trap baits have been based on fermentation products such as apple cider vinegar (ACV), wine, or yeast, since these ingredients are long-lasting and low-priced (Beers et al. 2011, Lee et al. 2011b). However, due to the lack of specificity and efficacy of these food-based lures there has been much research into the use of synthetic lures which aim to increase specificity and reduce by-catch.

4.1.1.1 Fermented/Food based lures

Fermented products are already known to play an important role in the monitoring of SWD, with recommended attractants including wine, vinegar, and fermenting yeast baits. Apple cider vinegar (ACV) has been the most widely recommended bait to attract adult SWD into traps because of its ubiquity, simplicity, and ease with which it may be observed (Beers et al. 2011). However, ACV is not an optimized lure for catching SWD and results in a large volume of by-catch (Lee et al. 2012). Work has tested combinations of wine, vinegar, acetic acid, and ethanol (Landolt et al. 2012b) and different combinations of wines and vinegars (Landolt et al. 2012), with data suggesting a rice vinegar and a merlot wine are more co-attractive than other tested combinations. However, more recent work by Huang et al. (2017) indicate that the addition of rice vinegar to merlot red wine reduces captures of SWD. Even though there was a small increase in fly capture with wine:vinegar at 80:20 ratio rather than at 40:60, the ratio used by previous researchers (Cha et al. 2012, Landolt et al. 2012b, Iglesias et al. 2014).

It is not surprising that yeast fermentation products induce a strong response in SWD, considering the importance of yeast as a food resource and potential indicator of habitat quality (Hamby and Becher 2016). Yeasts generate rich volatile chemicals which play critical roles in host preferences, mate location, and oviposition by flies (Scheidler et al. 2015). Recently, it has been revealed that there is a *Drosophila*-yeast mutualism, SWD contain specific yeast flora with *Hanseniaspora uvarum* the most abundant, followed by *Pichia terricola* and *P. kluyveri* (Hamby et al. 2012), and are attracted to these yeast species (Scheidler et al. 2015, Mori et al. 2017). However further development of these lures is needed.

The use of host plant volatiles from both fruit and leaves have also been the focus of research (Revadi et al. 2015); these volatiles could be a more selective bait than wine and vinegar. Tests on fly responses to host volatile compounds have indicated that raspberry fruit volatiles can be significantly more attractive to SWD than strawberry, blueberry, or cherry volatiles (Abraham et al. 2015).

Popular commercially available non-synthetic lures include but are not limited to:

- Droso'attract (Droskidrink) - a mixture of 75% apple cider vinegar and 25% red wine (Grassi et al. 2014). It is manufactured and sold by Biobest. Biobest also have a red Lynfield-bucket type trap, DrosoTrap, which is recommended to be combined with the lure. Additional sugar is added to the product once in the trap to support fermentation processes.
- *Suzukii*Trap is sold by Bioibérica and combined with their trap (a red plastic bottle). *Suzukii*Trap is a liquid mixture comprised organic acids and protein hydrolysed (7% of protein) (De los Santo Ramos et al. 2014)

The aforementioned non-synthetic lure and trap combinations are marketed as wet traps. The non-synthetic attractants use the lure as the drowning agent. See Table 10 for further handmade fermented/Food based lures and Table 11 for commercial products available overseas.

Table 10: Non-commercial lures for spotted wing drosophila.

NAME	KEY REFERENCE(S)
Apple cider vinegar	(Cha et al. 2013, Cha et al. 2018a, Cai et al. 2019) (Landolt et al. 2012b)
Wine	(Landolt et al. 2012b)
Wine + ACV	(Cha et al. 2013), (Landolt et al. 2012b)
Wine+ ACV + sugar	(Cai et al. 2019)
Wine +red wine vinegar	(Harmon et al. 2019)
Wine + Brown rice vinegar	(Willbrand and Pfeiffer 2019)
Brown rice vinegar	(Akasaka et al. 2017), (Willbrand and Pfeiffer 2019)
Wine +yeast	(Harmon et al. 2019)
Wine +yeast balanced colour profile	(Harmon et al. 2019)
Wine + Yeast Supernatant	(Harmon et al. 2019)
Fermenting dough	(Cha et al. 2018b)
Yeast + sugar	(Harmon et al. 2019)

4.1.1.2 Synthetic lures

Synthetic lures have been developed based on odours taken from the head space of apple cider vinegar and wine. These include acetic acid, ethanol, acetoin and methionol (Cha et al. 2012, Cha et al. 2013, Cha et al. 2014, Cha et al. 2015). These odours form the base of two commercially available synthetic lures; Scentry® Biological's spotted wing drosophila lure (L962) and the Trécé-Pherocon® spotted wing drosophila lures. The Pherocon lure is available as either a high specificity-low capture lure, or a broad-spectrum lure that captures more SWD as well as non-target species.

In addition to the odours identified by Cha et al. (2013; 2014; and 2015), a new synthetic odour combination has been identified and tested. The mixture comprises acetoin, ethyl octanoate, ethyl acetate, penenthyl alcohol and acetic acid. In trials assessing against the current commercial lure provided by Scentry®, the odours were placed in yellow jacket traps (Feng et al. 2018). The authors found that the lures had a greater percentage catch of SWD to other species captured than the Scentry® traps. However, the sensitivity of the lures was low and caught significantly fewer SWD than the Scentry® trap.

Many synthetic lures are recommended to be used with water and unscented soap to break water tension as a drowning solution, however, dry trapping e.g. with sticky traps has also been achieved for the Scentry® lures. There are a number of other lure providers, however, there is either little information on their products or they do not ship to Australia. See Table 11 for details of commercially available non-synthetic and synthetic SWD lures.

Table 11: Commercial lures/bait available for spotted wing drosophila

NAME	COMPANY	ACTIVES	COUNTRY	REGISTRATION IN AUSTRALIA	KEY PUBLISHED EFFICACY INFORMATION
Suzukii Trap®	Bioiberica	Peptides: 2% p/p Organic acids: 5% p/p	Spain	Not required	Kirkpatrick et al. 2017, Lasa et al. 2017, Tonina et al. 2018b
Dros'Attract®	Biobest	75% apple cider vinegar and 25% red wine	Belgium	Not required	Known as Droskidrink in published papers. (Grassi et al. 2014, Kirkpatrick et al. 2017, Renkema et al. 2018, Tonina et al. 2018a)
Scentry® Spotted Wing Drosophila Lures	Scentry	Acetic acid, ethanol, acetoin and methionol	America	Not required	Cha et al. 2018a, Jaffe et al. 2018, Kirkpatrick et al. 2018a, Renkema et al. 2018, Wong et al. 2018
PHEROCON® SWD PEEL-PAK™ Broad Spectrum Lure	Trécé Pherocon	Broad-spectrum lure	America	Not required	Kirkpatrick et al. 2017, Tonina et al. 2018b
PHEROCON® SWD High Specificity Lure	Trécé Pherocon	3 components	America	Not required	Cha et al. 2018a
Spotted Wing Drosophila trap and Lure	Alpha Scents, Inc.	Lure and yellow or white sticky trap	America	Not required	Kirkpatrick et al. 2017
DrosaLure	Andermatt biocontrol	• Cider vinegar • Red wine • Sugar • Natural flavours		Not required	
Z-Kinol	Squid Biological and Pheromones	A kairomone attractant comprising a mixture of ethanoic acid, hydroxyl alcohols, thiol-alcohols, and ketones	Mexico	Not required	Lasa et al. 2019
SPLAT SWD (Hook SWD)	ISCA	Sex-specific pheromone (males)	America	No (approval required)	Disi and Sial 2019, Klick et al. 2019

4.1.1.3 Traps

Trap design is vital for increasing the selectivity of SWD taps. Several types of traps have been tested for SWD including handmade plastic cups with 1 to 10 entry holes (the most commonly recommended), traps with mesh entries, and plastic cups with tents to provide shade and prevent water from entering (Kanzawa 1939, Lee et al. 2012). Dome traps and commercial "spice" jar traps have also been evaluated (Landolt et al. 2012b, Basoalto et al. 2013) with varying degrees of success. Other trap modifications include the addition of a yellow sticky card hanging inside the trap and odourless dish detergent to the drowning solution to help prevent escape (Landolt et al. 2012a, Landolt et al. 2012b, Lee et al. 2012, Van Timmeren and Isaacs 2013, Iglesias et al. 2014). Coloured sticky traps have also been assessed. For a list of homemade and commercially available traps see Table 12.

Table 12: Summary of the most commonly used handmade and commercial traps available for SWD.

NAME	DESCRIPTION	
5 cm sticky discs	Discs of various colours, red, purple, and black disks, clear and white	
PCV bottles	PVC bottles with 6-7 holes of 5 mm diameter and a capacity of 1.0-1.5 L	
Clear Cup trap	Also referred to Deli cup traps typically made out of clear cups	
Haviland	Container with mesh lid and rain tent	
modified Haviland	As above but with 10 side holes and no tent	
two-component trap (2C trap)	Trap comprising a cup with drowning solution and a ventilated tube device in the lid	
Red cup	Red plastic cup black strip with clear lid and entry holes around the cup	
Van Steenwyk	White container with mesh lid and rain tent	
PRODUCT	**COMPANY**	**DESCRIPTION**
PHEROCON ® SWD Trap	Trécé Pherocon	Clear with red attractant and white lid
Scentry® Spotted Wing Drosophila trap	Scentry	Clear with red label and white lid
Droso-Trap	Biobest	Red trap
Drosal Pro cup trap	Andermatt biocontrol	Clear cup black lid
Dorsal trap	Andermatt biocontrol	Clear cup white lid
Drosinal trap	ICB Pharma	Yellow container black collar with red lid
Profatec traps	Profatec AG	Clear cup red lid
Cera Trap	Bioiberica	Clear container with yellow lid containing liquid food based attractant

4.1.2 Surveillance system comparison

4.1.2.1 Lure comparisons

Presently, the main issues with traps and lure technology for SWD are:

- low specificity and
- low correlation with fruit infestation.

The efficacy rates of traps and lures have been shown to be highly variable being dependent on host crop, reproductive status of *D. suzukii* and other physiological parameters and behavioral priorities that may impact bait attraction. Age, feeding status and mating status of SWD are known to affect survival, phenology and other life history parameters (Hamby et al. 2016). Seasonal morphology type (summer morph or winter morph) of adult SWD may also affect behavioral priorities (Shearer et al. 2016, Wallingford et al. 2016). Because of this the type of lure/bait will potentially depend on the objective of trapping and the time of year. When considering surveillance for first detections of SWD, a bait that elicits a high response from hungry or reproductively immature flies in spring may be effective. However, it is not known if fermentation or fruit odour-based baits are highly attractive to all adult SWD, or just to ones with certain physiological conditions. Such knowledge can make trapping more targeted and effective throughout SWD's entire active season.

Food based and fermented products are cheap and readily available, however, there are drawbacks including being attractive to both adult SWD and non-target insects, which increases the time spent sorting through trapped insects (Lee et al. 2012, Cha et al. 2014, Iglesias et al. 2014, Burrack et al. 2015). Apple cider vinegar is an easy-to-use attractant, but it is relatively inefficient at capturing SWD compared with homemade yeast-sugar and yeast-flour mixtures or commercially available, synthetic lures. Some synthetic pouch lures (e.g.

Pherocon® SWD dual-lure and Scentry® Lure) are based on a four-compound blend, but they vary in efficiency at capturing SWD. Liquid attractants (*Suzukii* Trap®, DroskiDrink and Dros'Attract), typically based on mixtures of alcohols and fruit juices or extracts, also vary in their effectiveness at capturing SWD.

Commercial SWD lures have been shown to attract large numbers of non-target *Drosophila* flies in the field. In fact, commercially available lures capture between 28.7– 41.3% non-SWD drosophilids (Lee et al. 2013), and sorting these non-SWD flies from the target SWD requires a large amount of time and labour. Examples of these lures/baits include: Scentry® Lure, *Suzukii* Trap®, and the Pherocon® SWD. The commercially available lures have also failed to accurately predict fruit infestation in most United States fruit growing regions. However, in some northern fruit growing latitudes, where winters are able to knock-down SWD populations, the commercially available Scentry® Lure can detect adults 1–5 weeks before fruit infestation (Cha et al. 2018a). Lure efficiency varies depending on region and crop (Shawer et al. 2018b). For example, although the Scentry® Lure detects SWD 1–5 weeks before fruit infestation in northern blueberry crops, the lure detects SWD the same week of fruit infestation in raspberry (Cha et al. 2018a). Further, early detection is not meaningful or feasible in southern fruit growing regions of the United States because SWD populations are present year-round in those warmer climates.

Comparisons that focussed on the role of odour rather than trap colour determined that those baited with the Scentry® lure, yeast (12.5g active dry yeast, 50G sugar and 355ml distilled water), and Alpha Scents® lure outperformed those baited with Pherocon® or *Suzukii*® Trap (Kirkpatrick et al. 2017). Further trials comparing Scentry® to Pherocon® in different crop types showed that in a blueberry crop, the Scentry® lure detected SWD up to 10-days before the Pherocon® lure and 3-weeks prior to detection of larvae in fruit. However, in a raspberry crop, Scentry® detected SWD only 4-days prior to Pherocon® and on the same day as larvae were detected in fruit (Cha et al. 2018a).

A trial compared Biobest, Biologische Essigfliegenfalle, Pherocon® and *Suzukii*® Trap and apple cider vinegar. All lures outperformed apple cider vinegar. However, Pherocon® alone (without apple cider vinegar as a drowning solution) had significantly lower catch than the other commercial lures. All lures had low selectivity (Tonina et al. 2018b). Biobest®, Biologische Essigfliegenfalle and apple cider vinegar needed to be replaced approximately weekly, whereas Pherocon® and *Suzukii*® Trap needed to be changed approximately every 4-6 weeks. Further, Pherocon® and *Suzukii*® Trap worked better in cooler temperatures in the early spring, detecting flies before Biobest. The authors recommended *Suzukii*®. A further test with *Suzukii*® Trap when tested against a mix of apple cider vinegar and 10% ethanol plus 0.417 g yeast and 1.1 g sugar and 20 ml water showed that The apple cider vinegar, ethanol, yeast, sugar and water combination caught 4-7 times as many SWD as the *Suzukii*® Trap lure in a guava orchard (Lasa et al. 2017).

Combinations of lures has also been shown to increase effectiveness of trapping for example the combination of Scentry® Lure and *Suzukii*® Trap caught more SWD than the additive amount of either product alone, suggesting a synergistic effect. The Scentry® lure in combination with yeast and sugar plus water and unscented soap as a drowning solution catches both males and virgin and mated females. The addition of yeast and sugar to the Scentry® lure improved catch over Scentry® alone (Jaffe et al. 2018), but as with all of the other lures, by-catch is an issue.

The odours from yeast is good at attracting young SWD and the host odours in Scentry attract mature SWD (Wong et al. 2018). This was further supported by Clymans et al. (2019) findings that SWD is attracted to fermentation volatiles in search of (protein-rich) food and to fruit volatiles in search of oviposition substrates.

A trial investigated the presence of SWD in winter strawberry crops from 24 December until 17 March 2015-2016 in central (warmer) and northern (cooler) areas of Florida, USA (Renkema et al. 2018). The average minimum temperature in the central site was 11.5°C, 8.6°C and 12.3°C for early, mid and late winter; and the northern site was 8.8°C, 6.2°C and 9.9°C for early, mid and late winter. Biobest statistically out performed Scentry in catching female flies but not male flies at the warmer site and males at the cooler site (no data on females). However, overall catch was very low with the greatest difference in trap catch being recorded between the males at the cooler site (Biobest, 0.36/trap/day; Scentry 0.13/trap/day). Female winter morphs that were trapped at the central (warmer) site were checked for the presence of eggs. Approximately 65% of the females had eggs present of which approximately 20% were carrying mature eggs at early, mid and late winter assessments. Of note, there was increased catch near the edge of strawberry plots where they bordered woodlands.

There is a continued need to test trap type and attractant combinations ('trapping systems') in specific regions and crops so that growers can select optimal tools for SWD monitoring programs.

4.1.2.2 Trap comparison

There are several factors in trap design that have been tested, these include:

- Colour
- Number of entry points available to the fly
- Bait volume
- Bait surface area
- Headspace

Studies have shown that red or black traps and traps with an expanded entry area, a larger surface area for liquid attractants and increased headspace improved capture rates (Lee et al. 2013, Renkema et al. 2014, Addesso et al. 2015, Kirkpatrick et al. 2016, Rice et al. 2016).

Recent laboratory studies investigating differences in colour preference for SWD showed a higher affinity towards darker colours such as red, burgundy, and black compared with lighter colours like white and light blue (Basoalto et al. 2013). The use of alternating bands of red, black, and red (called 'Zorro' traps) near the trap entrance significantly increased SWD catches in the field (Basoalto et al. 2013). Further, in a series of trials to identify the best colour to attract SWD with Scentry® lures, red spheres were identified as the best followed by black. Yellow, blue, and purple were statistically similar to the red and black, but green and white were the least attractive colours (Kirkpatrick et al. 2017).

Colour contrast played a significant role in colour preference. Little et al. (2020) suggest that SWD have limited ability to distinguish red consistent with visual sensitivity range within the melanogaster subgroup of the *Drosophila* genus. It is proposed that colour contrast rather than colour appearance may be of greater importance in orientation and attraction. Recent research supports the attractiveness of red and black against a white background. However, monitoring traps used in fruit crops are normally deployed amongst foliage rather than a white background. This may explain why monitoring traps in a combination of clear plastic and yellow have been used with similar efficacy (Lee et al. 2013, Iglesias et al. 2014).

Various results have been found when comparing trap entry holes. Field trapping experiments placed across seven US states found that traps baited with vinegar caught more flies if they had more entry points versus traps with fewer entry points (Lee et al. 2012). In another study, traps with mesh sides caught more SWD than traps with mesh on the lid. These results suggest that higher release rates of the volatiles from the attractants increase trap attractiveness and subsequently trap catch.

Lee et al. (2012) evaluated the efficiency of seven traps for monitoring SWD on farms for early detection. Among all the traps, a Rubbermaid container with a mesh lid and rain tent trap (Haviland trap) caught the greatest numbers of SWD flies followed by the red, Van Steenwyk, and clear trap. The modified Haviland and commercial trap had low captures. In a bid to improve trap designs for monitoring SWD. Lee et al. (2013) evaluated traps with different colours, two different bait surface areas, and two different entry positions. Yellow traps with a large surface area for baits and side entry points caught more SWD than any other traps (Lee et al. 2013).

Addition of soap to some of the baits, like apple cider vinegar, may help catch more SWD. Soap may not be helpful with baits like yeast-sugar-water, as it is a broth of living organisms. Dome traps are thought to work well because it may be more difficult for SWD to escape from the trap.

4.1.2.3 Interaction between trap and lure design

As the number of available attractants increases and their compositions evolve, there is a continued need to test trap type and attractant combinations ('trapping systems') in specific regions and crops so that growers can select optimal tools for monitoring programs.

Iglesias et al. (2014) found that the addition of a yellow stimulus to sugar and yeast baited traps increases SWD attraction versus clear baited traps in blueberry fields. Similarly, red sphere traps baited with the commercial Scentry® Lure captured more SWD adults than clear and yellow traps baited with the lure in cherry orchards (Kirkpatrick et al. 2017).

In a separate test in cherry, red sphere traps with the Scentry® lure captured significantly more flies than the deli-cup traps with the Scentry® lure or with the yeast sugar bait, and red panel traps with the Scentry® lure captured significantly more flies than deli-cup traps with the Scentry® lure. In raspberry high tunnels, red sphere traps with the Scentry® lure captured significantly more flies than deli-cup traps with the Scentry® lure. Red traps baited with the same lure as clear deli-cup traps consistently captured more SWD (Kirkpatrick et al. 2017).

These findings demonstrate that a trap integrating both visual and olfactory cues is a superior tool for monitoring SWD. Moreover, sticky, dry trap design requires far less labour and maintenance than does a liquid-based deli-cup trap.

Table 13: Surveillance tools comparison for SWD adults

PRODUCT	ADVANTAGES	DISADVANTAGE
Lure Type		
Apple cider Vinegar (ACV) and ACV mixes	- Cheap - Easy to obtain - Both a bait and drowning solution	- Bait must be mixed by the operator - Low specificity i.e. high by-catch - Greater time to sort through trapped insects - Relatively inefficient compared with yeast-sugar and yeast-flour mixtures or commercially available, synthetic lures
Fermented Bait	- Cheap - Easy to obtain	- Bait must be mixed by the operator - Can be messy to prepare - Low specificity i.e. high by-catch - Greater time to sort through trapped insects
Commercial non synthetic	- Ready to use - Both a bait and drowning solution	- More expensive than home-made attractants - Low specificity i.e. high by-catch - Greater time to sort through trapped insects
Commercial synthetic lure	- Improve early detection - Long lasting lure - Ready to use	- Often require addition of capture liquid depending on product - More expensive than home-made attractants - Low specificity i.e. high by-catch - Greater time to sort through trapped insects
Pheromone lure	- Highly specific	- Not well tested
Attract and kill		- Requires permit for use
Trap Type		

PRODUCT	ADVANTAGES	DISADVANTAGE
Homemade plastic cup	- Cost effective - Reusable	- Construction of traps is time consuming - Not as durable as commercial traps - Variability in construction can alter trap catches
Sticky trap	- Cost effective - Easy handling - Less labor and maintenance than liquid base trap	- Non reusable - Can only be sued with certain lures
Commercial clear trap with red lid	- Reusable - Easy handling - Red colour is attractive to SWD - Durable	- More expensive than home-made traps
Commercial clear trap with black lid	- Reusable - Easy handling - Dark colours are more attractive to SWD than light colours - Durable	- Not as effective as red traps - More expensive than home-made traps
Commercial clear trap with white lid	- Reusable - Easy handling - Durable	- More expensive than home-made traps - White has not been shown to be as attractive as other colours
Commercial clear trap with yellow lid	- Reusable - Easy handling - Yellow colour is attractive to SWD - Durable	- Not as effective as red traps
Commercial Red trap clear lid	- Reusable - Easy handling - Red colour is attractive to SWD - Durable	- More expensive than home-made traps
Yellow container black collar with red lid	- Reusable - Easy handling - Increased catch has been shown with traps with banding of colors - Durable	- More expensive than home-made traps

4.1.3 Surveillance for larvae

Monitoring for adults using traps deployed with existing baits and lures cannot reliably predict infestation levels in fruit (Hamby et al. 2014, Burrack et al. 2015). Monitoring for larvae can provide a more reliable indication of fruit infestation. Fruit sampling methods have been reported in which fruit are placed in brown sugar water, salt water, or hot water, followed by counting the larvae that subsequently exit the fruit (Hueppelsheuser 2010, Dreves et al. 2014

Sampling methods for SWD larvae include extraction, dissection and natural emergence which rely on visual assessments of larvae (Table 14). Each method has various advantages and disadvantages. Larval sampling can be done by harvesting fruit and lightly crushing to expose the pulp. This is then immersed in either a salt solution 22.5 ml salt to 473 ml water and leaving for 10 mins (Hamby et al. 2014) or a sugar solution 1 kg sugar and 5.5 L water. Current larval monitoring techniques using brown sugar or salt solutions allow for visual detection of late-instar larvae, but they are time consuming and tend to miss smaller larvae. For SWD management, this often means missing the small (first and second instar) larvae and only detecting third instars that can be most easily seen. Van Timmeren et al. (2017) described an improved salt extraction method using a coffee filter, and microscope that can reliably and efficiently detect small and large larvae of SWD in fruit samples. By sifting the sample liquid through an inexpensive coffee filter, larvae of all instars can be counted quickly and accurately. This method is 1.7 times faster than using a visual tray based method and can detect more larvae because first instar larvae can be detected.

Another simple detection method for *Drosophila* larvae is to store intact fruits for 24 hours at room temperature and then to immerse them in a transparent container (for example a cup) filled with tap water and one or two drops of liquid soap or dishwashing detergent. After ten to fifteen minutes, the larvae can be counted on the bottom of the container.

These success of these sampling methods relays on having skilled diagnosticians who can quickly and accurately identify SWD larvae. The detection of larvae in fruit can be difficult for unskilled workers or time-restricted growers. Although dissection and emergence gave higher counts of larvae, flotation methods using sugar or salt were significantly faster and therefore a more viable option for growers to use in the field. While these methods may not give an accurate quantitative result, they are effective in the detection of infestation of larvae in fruit, which is typically all a grower needs to make decisions about a crop. Larval infestation rates and numbers of adults trapped with apple cider vinegar or with yeast-baited traps are not well correlated (Hamby et al. 2014).

Table 14: Sampling methods for surveillance of SWD larvae

SAMPLING METHOD	DESCRIPTION	ADVANTAGES/ DISADVANTAGES	REFERENCE
Filter Method	Collect fruit, lightly crush fruit, add salt solution, filter through course filter then through coffee filter	One disadvantage of this filter sampling method is that fruit pulp can potentially clog the filter. This concern can be reduced by only lightly crushing fruit. Provides a real-time measure of in-field infestation for this pest	Van Timmeren et al 2017
Extraction	Extraction methods for detecting 1st-2nd and 3rd instar SWD larvae flotation in sugar (sucrose), salt (NaCl) or detergent solution,	Extraction using a concentrated sugar solution (180 g/L) gave consistent counts of larvae, and was significantly quicker than natural emergence and dissection methods. Salt extraction performed as well as sugar in most cases	Shaw et al. (2019)
Freezing		Freezing was consistently poor and not an effective way of detecting 1st-2nd instar larvae.	Shaw et al. 2019
Natural emergence	Collection of infested fruit and subsequent natural emergence	Although natural emergence had one of the highest recovery rates it required a prolonged period before results were obtained.	Shaw et al. 2019
Dissection	Dissection of fruit under a microscope	The use of dissection, which was as effective as emergence in larval recovery, requires intensive labour and a microscope to, effectively, identify the younger larvae within the fruit. As it is unlikely that growers would have the correct equipment and time to perform this method it may not be practicable.	Shaw et al. 2019

4.2 Surveys for early detection of an incursion

There are so many inconsistencies with the first detections of SWD around the world that any attempt to predict the most likely incursion sites in Australia or New Zealand with precision is speculative. Further to this research on trap capture rates suggest that any level of trap capture may be indicative of a high population of SWD in the surrounding area (Kirkpatrick et al. 2017, Kirkpatrick et al. 2018a) Therefore, the chances of trapping the first individuals are considered slim without a high density of traps.

In a report by **cesar** *Estimating the effect of surveillance effort on detection probability* it was shown that that even a large surveillance effort of 1 trap per hectare only provides ~50% confidence that the trap will detect densities of SWD of 100 per ha in one week (Figure 26), which are sufficiently large to cause crop losses (Kirkpatrick et al. 2018b). Naively assuming 1 trap per hectare in Australia's approx. 70,000 ha of horticultural regions (Bureau of Agricultural and Resource Economics and Sciences 2010) would result in an annual surveillance operating cost of over $70 million if annual operating costs per trap with weekly inspections are taken as $1000.

Despite the limitations, at present trapping and notification by the public are the only realistic early detection methods available.

When considering potential sites of first detection in Australia climatic suitability, land use, host availability, season, points of entry, origin of fruit imports and fruit disposal should be taken into account. In summary initial surveillance priorities for SWD should consider the following details:

- The most important pathway into Australia will likely be through fruit that is imported and then on sold to consumers. This indicates that urban areas are likely to be the environment where SWD populations will first occur.
- The type of sites where SWD is likely to first arrive are difficult to determine from previous incursions, as the first site of detection is not necessarily the invasion epicenter.
- It is important to note that the invasion site and the 'spreading centre' of an invasive species are not always one and the same (Cini et al. 2014). The first invasion site is not always suitable for spread, meaning the invasion may stem from a secondary invasion site rather than the initial arrival point (Cini et al. 2014).
- The location of high throughput ports or airports may be important to note, particularly those ports where fresh fruit is being imported from countries where SWD is present.
- The location of fruit distributors, wholesalers and retailers may be important to note as disposal of unsold imported fruit via wholesaler or retailer cull piles may present a risk.

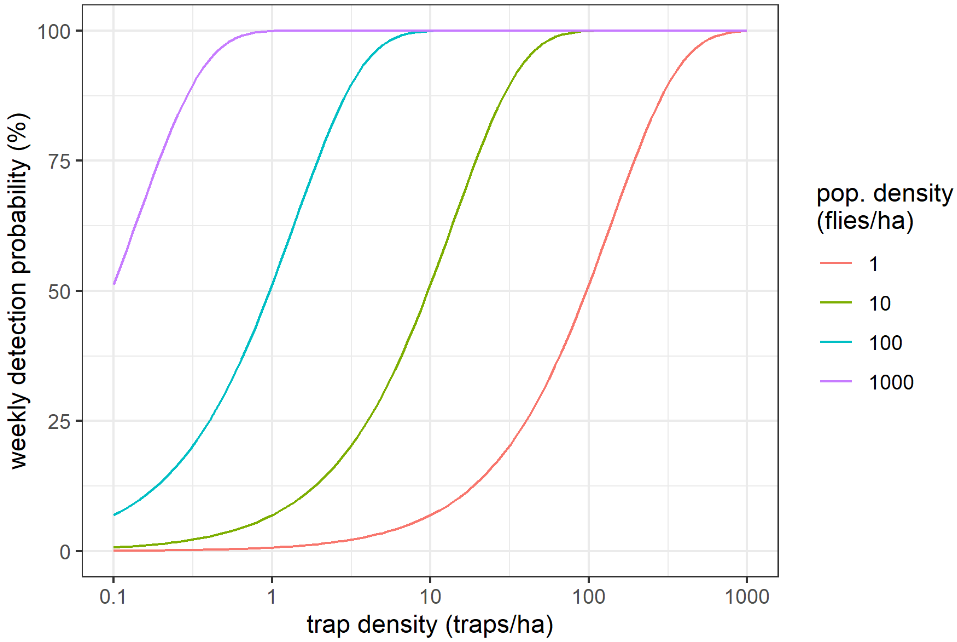


Figure 26: The estimated effect of surveillance effort on the probability of detection based on release and recapture study (Kirkpatrick et al. 2018b) for a single 20 × 30 cm double-sided, sticky, red panel trap (Great Lakes IPM, Vestaburg, MI) baited with a commercial SWD lure (Scentry Biologicals, Billings, MT) placed in the bottom third of the canopy of a cherry tree.

4.3 Delimiting surveys in the event of an incursion

In the event of an incursion, delimiting surveys will be required to inform the decision-making process.

All potential host species (refer to Section 2.2) should be surveyed, with particular attention paid to the species in which the pest was initially detected.

Area of trapping required to delimit spread

The area of trapping required to delimit spread has been explored by modelling conducted by **cesar.** The area invaded after 6 and 12 months has been estimated for 10 replicated simulations for every ~30 x 30 km region across Australia. The mean area invaded across replicate simulations is then reported for each grid cell which is used to generate two maps of Australia where the colour of each pixel denotes the required trapping area for delimitation after 6 and 12 months for an incursion originating at the pixel location (Figure 27)

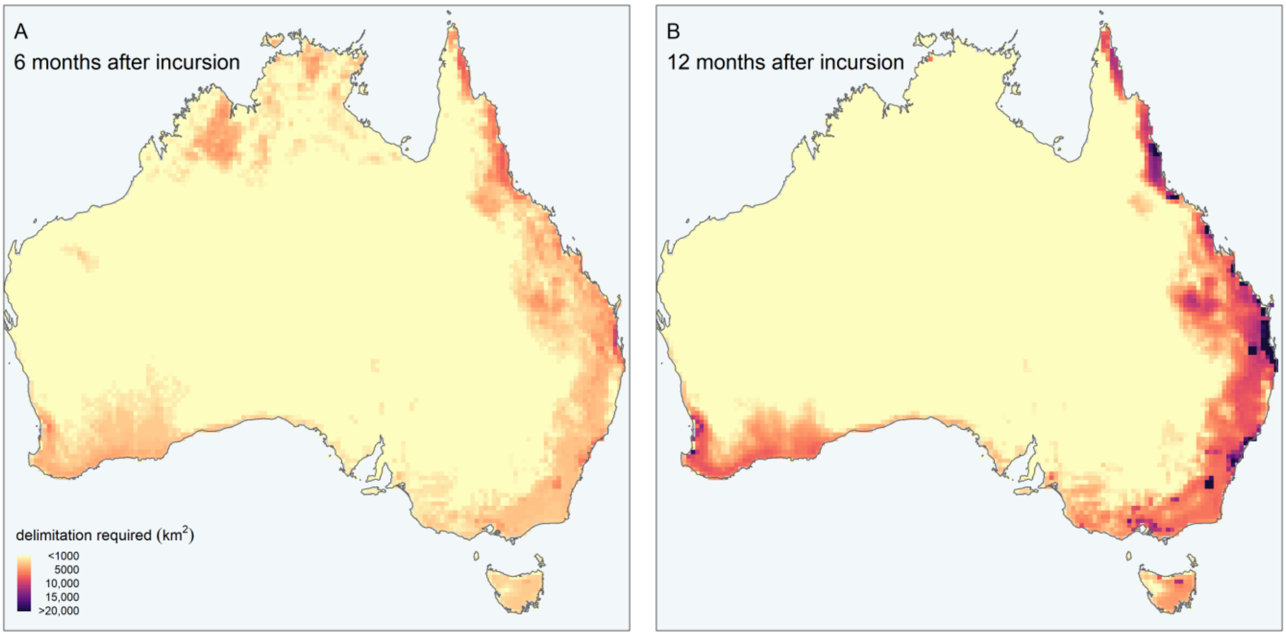


*Figure 27: For each grid cell an incursion is simulated with the grid cell as the origin. The resulting invasion extent after 6 months (**A**) and 12 month (**B**) is indicated by the grid cell colour. The area of trapping required to delimit spread depends on the duration since the initial incursion, and on the environmental and economic conditions at the incursion point.*

Following a summer incursion, SWD is estimated to have spread on average 2,041 km^2 after 6 months and 4,674 km^2 when considering cells where spread is possible (e.g. ignoring the interior of Australia, which is too hot and dry). In addition to time since incursion, the environmental and economic conditions at an incursion location was a major driver in spread rates which will influence the area required to be under surveillance for delimitation purposes. For example, coastal regions on the east coast with high population densities would require greater delimitation efforts if an incursion originated there. Conversely, if an incursion commenced at inland locations with poorer climatic suitability and lower population densities, the incursion extent could be more readily delimited.

Delimiting spread of SWD will be difficult as trapping efficiency has shown to be very low, only detecting around 1% of the population size. This limits the ability of traps to successfully capture the presence of SWD. Despite this limitation, the following points provide a set of factors that should be considered for delimiting surveillance.

- Surveillance should be a combination of the following:
  - Visual inspection in high risk areas (e.g. edges of crops or orchards with mature fruit or vegetables).
  - Trapping with two forms of lures one a yeast based lure the other a synthetic.
  - Fruit sampling via floatation - as larval extraction is a good indicator of the actual threat to crops.
- Surveillance to delimit a detection of SWD should take into account tracing information as outlined in Section 5.1.1 to determine potential pathways for movement of material from the site of the initial detection.
- At each site, chose a crop that is a preferred host plant of SWD. It is also important to have traps in wild vegetation surrounding crop (refer to Section 3.2).
- At low densities, SWD have a relatively low detectability. Figure 26 illustrates the number of traps per ha required to detect SWD at various population densities.

- If suspicious damage is detected, fruit samples should be collected (see Section 5.13), and traps should be placed around the affected area, in an attempt to capture adults and diagnose the fly responsible for the damage.
- If SWD are confirmed, visual surveillance along with traps should be used to monitor around the initial detection location
- Surveillance should be accompanied with awareness material, signs and personal visits to households and businesses within the surveillance zone and buffer zones.
- Detection year-round may be possible in parts of Australia. In winter months, trapping should occur within non-crop hosts.
- It is important to have traps deployed to capture adult SWD after the winter diapause.

4.4 Ongoing surveillance for SWD

The efficacy rates of traps and lures have been shown to be highly variable, with efficacy dependent on host crop, reproductive status of SWD and other physiological parameters and behavioral priorities that may impact attraction to baits/lures. Points for consideration for any type of surveillance include:

- Visual inspection of fruit is a useful method in high risk areas (e.g. edges of crops or orchards with mature fruit or vegetables).
- If trapping is used, it should comprise two forms of lures - one a yeast based lure, the other a wine/apple cider vinegar (ACV) based lure or a commercial lure based on fruit volatiles.
- Fruit sampling via flotation tests for larvae using sugar water is a useful tool as larval contamination is a good indicator of the actual threat to crops.

4.5 Collection and treatment of samples

Protocols for the collection, transport and diagnosis of suspect Emergency Plant Pests (EPPs) must follow PLANTPLAN (Plant Health Australia, 2019). Any personnel collecting samples for assessment should notify the diagnostic laboratory prior to submitting samples to ensure expertise is available to undertake the diagnosis.

5 POTENTIAL OPTIONS FOLLOWING DETECTION

5.1 Considerations for eradication

Rapid spread within overseas countries has been facilitated in many instances by a lack of domestic quarantine or movement control being imposed. For example, when reviewing the EPPO records of first detection, a number of entries imply that no official measures or phytosanitary actions were taken. It seems that by the time SWD was first detected in many countries it was already relatively widespread, making containment difficult. Also, in Brazil, reduced access to insecticides registered for use against SWD was also recognised as an issue (Zanuncio-Junior et al. 2018). This occurred because little was known about the recent adaption of this *Drosophila* species to attack ripening fruit. By the time research was undertaken and awareness was raised, SWD was well established within and between many countries.

Australia is fortunate to be in a position to learn from these overseas experiences, and therefore increase the preparedness of both industries and governments for its potential as an emerging high priority pest.

To have any potential to eradicate or slow the spread of SWD after detection, it must be found early in its invasion and host plant movement controls must be placed immediately. This species is highly fecund, develops rapidly, and uses a large number of fruits from commercial to weed species as larval hosts.

For eradication to be considered, in Australia there are a range of factors that need to be evaluated, and an assessment of these factors has been conducted as per the technical feasibility of eradication criteria outlined in PLANTPLAN 2019 and is presented in Table 1. It is important to note that this table has been pre-emptively compiled and that there no current incursion points. Information in section 2 of the table is therefore inclusive of general information that is relevant to any detection point.

This pre-populated table may be used as a basis for considering the technical feasibility of eradication during an incursion, and modified accordingly based on the incursion context, guidance information included in this document, and any new information that arises after publication of this document.

Modelling work conducted by **cesar** built upon the previously developed spatially explicit simulation framework of population growth and spread, to include surveillance, quarantine, and economic cost processes of SWD management and explore the cost-benefits of a range of surveillance and quarantine strategies. Despite assuming a high efficacy and low cost of quarantine and eradication, as well as optimistic early incursion detection at ports of entry, quarantine and eradication could not be demonstrated as economically rational for simulated incursions of SWD into Australia's major coastal cities for a 24-month time horizon.

The management response that minimised total costs included high pest awareness without eradication or quarantine. However, at shorter time horizons (i.e. 12 months) quarantine with moderate surveillance (trap density traps/km^2 = 0.001) became cost-effective for Melbourne and Perth incursion scenarios, reflecting the importance of time horizons in the calculation of benefit-costs. There was also some support for eradication in Perth, due to its relative isolation from eastern soft fruit industries. Though It is important to reiterate that the cost-effectiveness of quarantine and eradication depends on the early detection, reliability of public reporting at high densities, and high compliance with quarantine restrictions. In contrast to quarantine, investment in increased pest awareness only saw a net benefit for Adelaide and Melbourne simulations by 12 months. This reflects that time taken to recover the large initial investment in education. By 24 months, investment in pest awareness resulted in the lowest overall impacts across all incursion scenarios tested. This general low cost-effectiveness of quarantine and surveillance can be explained by SWD's large population growth potential, ability to travel via human-mediated pathways, and low sensitivity of current surveillance methods. In contrast to eradication and quarantine, increased pest awareness saw large return on investment due to enhanced early detection and reduced crop losses through appropriate pest management (Table 15).

Table 15: Lowest cost management response at 12- and 24-month time horizons calculated from the mean of five replicate simulations for incursions at major capital cities. Management responses indicate the actions taken for the lowest impact scenario.

INCURSION POINT	12 MONTHS		24 MONTHS	
	Lowest cost management response*	Total cost ($ million)	Lowest cost management response*	Total cost ($ million)
Adelaide	Awareness	2.61	Awareness	5.25
Brisbane	Awareness	3.48	Awareness	13.88
Hobart	-	1.37	Awareness	7.21
Melbourne	Quarantine trap density 0.001	0.54	Awareness	5.32
Perth	Quarantine trap density 0.01	1.67	Awareness	4.50
Sydney	-	0.56	Awareness	5.12

*Trap density denotes the mean density of traps in each square kilometre. Eradication denotes reduction of populations to 99.99% of the maximum population in locations at which presence of *D. suzukii* has been confirmed through surveillance trapping. Quarantine denotes a 99.99% reduction in populations dispersing by human means in locations where the fly has been reported or trapped. Awareness denotes the level of pest awareness among the public, where a high pest awareness leads to early public reporting once the pest exceeds damage levels of 0.1 individuals/m^2 and crop losses reduced from 10% to 5%

5.1.1 Tracing

Detection and delimiting surveys are required to delimit the extent of the outbreak, ensure areas free of the pest retain market access, and ensure that appropriate quarantine zones are established.

Extensive tracing (trace forward and trace back) may be feasible as SWD can be readily dispersed by the movement of infested fruit and to a lesser extent soil. The focus should be on high risk linkages including premises linked directly with the initial detection.

Further information on possible risk pathways are presented in Section 3.1.

5.1.2 Quarantine and movement controls

Three PRAs have been prepared on this pest:

- Biosecurity Australia, 2013. Final pest risk analysis report for *Drosophila suzukii*.
- Damus, M. 2009. Plant Health Risk Assessment: *Drosophila suzukii* (Matsumura), Spotted Wing Drosophila. Unpublished, Canadian Food Inspection Agency, 2009.
- EPPPO 2011 Pest Risk Analysis For: *Drosophila suzukii*.

Australia's biosecurity obligations under the International Plant Protection Convention and the International Standards for Phytosanitary Measures led to a risk analysis being conducted by Australia's then Department of Agriculture, Fisheries and Forestry. The analysis of the quarantine risks associated with SWD, identified several traded commodity groups that could serve as a potential pathway for SWD into Australia. This has been built upon further in work conducted by **cesar** to include pome fruit and citrus and mushrooms (see section 3.1.1). It has been shown that previously overlooked commodities with low host-preference, are imported in such high volumes that they may pose import risks for SWD.

The proposed risk management measures obtained from the 2013 Final pest risk analysis report for *Drosophila suzukii* are:

- For fresh fruit potentially carrying life stages of SWD:
  - area freedom from SWD, or
  - a systems approach for fruit to ensure that fruit are not infested with SWD, or
  - application to fruit of a treatment known to be effective against all life stages of SWD,
    - Current approved treatments include methyl bromide fumigation for strawberry and cherry; or
    - sulfur dioxide/carbon dioxide fumigation followed by a six-day cold treatment for table grapes.
    - methyl bromide fumigation for stone fruit (peach and nectarine only). And,
- supporting operational systems to maintain and verify phytosanitary status.

Since this risk assessment, an Interstate Certification Assurance ICA for irradiation treatment (ICA-55) has been identified as a potential fruit treatment for SWD.

If Restricted or Quarantine Areas are practical, no fruit should be moved from the infested to non-infested areas without first being inspected and appropriately treated. The size of the Restricted Area will be dependent on the type and scale of the incursion.

Voluntary movement control should be considered for urban/residential detections. Voluntary controls would involve negotiation with residents to undertaken inspection and treatment of goods prior to movement from Infested Premises. Residents should be advised on measures to minimise the inadvertent transport of the pest from the infested area to unaffected areas. Voluntary compliance is likely to be implemented for urban areas using awareness campaigns to highlight high risk goods/situations and appropriate treatments.

5.2 Management strategies – expected industry requirements should SWD become established in Australia

Effective management of SWD overseas relies on various management strategies. Crop hygiene is considered to be of most importance and value, especially when coupled with cultural control practices such as microhabitat manipulation which has been shown to be an effective management tool for SWD. Many cropping systems have moved away from the use of chemicals that impact on Integrated pest management (IPM) systems. Because of this chemical control for SWD is often lower on the list for use as a management tool.

Pest management strategies required to develop successful Integrated Pest Management (IPM) programs including:

1. Make fields less favourable for SWD. This can be achieved through
   - Cultivar selection
   - Weed fabric
   - Pruning
   - Netting
   - Hygiene
2. Monitor SWD flies in spring to detect first activity
3. As fruit begin to ripen, sample for larvae
4. Protect ripening and ripe susceptible fruit. This can be achieved by
   a. Weekly pesticide applications
   b. Ensuring good coverage of sprays
   c. Reapplication of pesticide after rain
   d. Rotation of chemical classes

   e. Consideration of both adult and larval control options
5. Post-harvest methods

The cost of management is less than the cost of doing nothing. No single control method will work to reduce SWD populations. Rather multiple methods used as part of an IPM plan is recommended.

5.2.1 Chemical control options

Various insecticides are used commercially for the management of SWD overseas (Hamby and Becher, 2016). Currently there are around 19 active constituents which are used overseas in various hosts these include.

- Bifenthrin
- Spinetoram
- Clothianidin
- Cyantraniliprole
- Maldison (syn. Malathion)
- Spinosad
- Methomyl
- Beta-cyfluthrin
- Cyclaniliprole
- Esfenvalerate
- Lambda cyhalothrin
- Phosmet
- Zeta-cypermethrin
- Cyantraniliprole + Abamectin
- Diazinon
- Lambda cyhalothrin + Thiamethoxam
- Acetamiprid
- Fenpropathrin
- *Chromobacterium subtsugae* Strain PRAA4-1 and spent fermentation media
- Imidacloprid + Cyfluthrin
- Cypermethrin
- *Burkholderia* spp. Strain A396

Many insecticide sprays target only the adult flies. Eggs and larvae are difficult to control because they are inside the fruit. Therefore, insecticide applications should begin prior to SWD egg laying, or in response to SWD detections in monitoring traps. Egg laying begins when the first fruits begin to ripen and become attractive egg-laying sites and will continue until the last of the fruits ripen. Because SWD egg laying can continue for several weeks, rotating insecticide products is necessary to prevent the development of insecticide resistance, which could happen if a single product is used continually throughout the SWD egg-laying period.

Table 16 provides a summary of the effectiveness of the different actives for SWD control as well as providing information on the impact of the insecticide on beneficial organism and information on the data needed to support permit applications. A colour coding system has been developed where green are the best options (i.e. effective, low impact, limited additional data required), yellow are less preferred options followed by orange and then red as the least preferred options. This information can be used to determine the most suitable insecticide options to pursue for SWD control.

Table 16. Summary of effectiveness, impact and data requirements for identified insecticides

PRODUCT (MODE OF ACTION GROUP)	EFFECTIVENESS (UNIVERSITY OF CONNECTICUT 2018 A AND B)	COMPARISON OF OVERSEAS AND AUSTRALIAN RATES	DATA REQUIRED	IMPACT ON BENEFICIAL ORGANISMS
Bifenthrin **(3A)**	Excellent	Used in Australia at higher rates than overseas (one or more crops)	No additional trial data needed	Toxic (based on Biobest side-effects manual 2019)
Spinetoram **(5)**	Good-excellent	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	While generally considered non-toxic to slightly toxic (low cotton beneficial toxicity based on CRDC and Cotton info 2018) It has been noted as highly toxic to key predators such as *O. insidiosus* and *C. rufilabris*
Clothianidin **(4A)**	Good	Used in Australia at higher rates than overseas (one or more crops)	No additional trial data needed	Moderately toxic (based on CRDC and Cottoninfo 2018)
Cyantraniliprole **(28)**	Good-excellent	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Moderately toxic (based on CRDC and Cottoninfo 2018)
Maldison (syn. Malathion) **(1B)**	Good	Used in Australia at higher rates than overseas (one or more crops)	No additional trial data needed	Toxic (based on Biobest side-effects manual 2019)
Spinosad **(5)**	Good	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Non-toxic to slightly toxic (low cotton beneficial toxicity)
Methomyl **(1A)**	Excellent	Used in Australia (on one or more of the listed crops) at lower rates than used overseas	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Beta-cyfluthrin **(3A)**	Excellent	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Cyclaniliprole **(28)**	Good-excellent (approximation - not covered in University of Connecticut 2018 a or b)	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Esfenvalerate **(3A)**	Excellent	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Lambda cyhalothrin **(3A)**	Good-excellent	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Phosmet **(1B)**	Excellent	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Zeta-cypermethrin **(3A)**	Excellent	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Cyantraniliprole + Abamectin	Excellent	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Moderately toxic (based on CRDC and Cottoninfo 2018)

PRODUCT (MODE OF ACTION GROUP)	EFFECTIVENESS (UNIVERSITY OF CONNECTICUT 2018 A AND B)	COMPARISON OF OVERSEAS AND AUSTRALIAN RATES	DATA REQUIRED	IMPACT ON BENEFICIAL ORGANISMS
Diazinon **(1B)**	Good	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Lambda cyhalothrin + Thiamethoxam	Good	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Acetamiprid **(4A)**	Fair	Not used in Australia on target crops	Safety and residue	Moderately toxic - toxic (based on Biobest side-effects manual 2019)
Fenpropathrin **(3A)**	Excellent	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Toxic (based on Biobest side-effects manual 2019)
Chromobacterium subtsugae Strain PRAA4-1 and spent fermentation media	Fair to poor	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Non-toxic (based on label)
Imidacloprid + Cyfluthrin	Good	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Toxic (based on Biobest side-effects manual 2019)
Cypermethrin **(3A)**	Suppression (based on label. Not covered in University of Connecticut 2018 a or b)	Not used in Australia on target crops	Safety and residue	Toxic (based on Biobest side-effects manual 2019)
Burkholderia spp. Strain A396	Suppression	Product not used in Australia	Product is not in Australia. Would therefore need import permits, manufacturing, residue and crop safety data	Non-toxic (based on label)

Key:

	The review of chemical control options assesses four main criteria. Ideal candidates for chemical control of SWD within Australia will be highlighted by four green cells. Increasing numbers of yellow or orange cells indicates regulatory or practical barriers to the use of the control option. Inclusion of red cells likely indicates a poor candidate for the ongoing management of SWD, at least in the short term.
	Review indicates a good option for initial control efforts within Australia. The chemical has evidence of effectiveness against SWD, the product is used or approved within Australia, or the product has little or no impact on beneficial insects.
	Review indicates some impediments to the use of the chemical within Australia, including less than ideal control against SWD, some differences in usage patterns within Australia, requirements for some data to facilitate regulatory approval, or some impact on beneficial insects.
	Review indicates significant impediments to the use of the chemical within Australia, including only limited effect against SWD, non-use of the chemical on the potentially affected crops within Australia, or moderate toxicity to beneficial insects.
	Review indicates major impediments to the use of the chemical within Australia, including evidence that it might not be an effective control for SWD, lack of regulatory approvals within Australia, or high toxicity to beneficial insects.

5.2.1.1 Attract and kill technology

Attract-And-Kill is a control method similar to mass trapping (refer to Section 5.2.2.2) except that it does not rely on pest retention inside a trap. Lure and kill products are being developed to target only SWD thereby limiting the off-target effects from wide application of broad-spectrum insecticides. One such example is ISCA Technologies' SPLAT Hook SWD. This is an experimental pink-coloured bait spray formulation containing phagostimulants and spinosad 0.5% to lure and kill individuals- regulatory approval pending (Klick et al. 2019). Another attract and kill strategy under development is attractive red spheres impregnated with chemical insecticides. In the laboratory, Rice et al. (2017) showed that these attractive red spheres impregnated with several chemical insecticides including dinotefuran, spinetoram, spinosad, permethrin, lambda-cyhalothrin, and lambda-cyhalothrin at 1.0% active ingredient (a.i.) killed 100% of SWD that came into contact with them. In raspberry fields in West Virginia, spheres impregnated with 1.0% a.i. dinotefuran decreased SWD fruit infestation in treated plots (Rice et al. 2017)

5.2.1.2 Recommendations for future permit applications

Generally, before pesticides are legally allowed to be used in Australia labels or permits need to exist allowing the proposed use pattern. This means that when new pests enter Australia Emergency use permits need to be put in place.

In order to put APVMA permits in place applications must be submitted to the APVMA that address a range of criteria including evidence that the pesticide being proposed is effective and that the proposed use will not have residue, environmental, crop safety and operator safety issues. The most straightforward applications for emergency use permits are those where an overseas label specifies a pesticide:crop:rate combination (i.e. use pattern) that is the same as, or less than, the existing Australian use patterns. If the proposed use pattern is very different than local crop safety and residue trials may need to be established to collect data to support the proposed use pattern.

The following recommendations have been made based on a comparison of overseas and Australian use patterns

1. Consider developing an APVMA permit for Maldison on berries (including strawberries, rubus berries, ribes berries, blueberries), stone fruit (including apricots, cherries, nectarines, peaches and plums) and grapes.
2. Consider developing an APVMA permit for bifenthrin on rubus berries, gooseberries and blueberries
2. Consider developing an APVMA permit for clothianidin on peaches

It is also recommended that further research is undertaken to determine suitable control options for SWD on citrus, fruiting vegetables (capsicum, chili, eggplant, tomato), figs, kiwifruit, pome fruit (apples and pears), pomegranate and tropical/sub-tropical species (e.g. guava and feijoa). As no pesticide options were identified that are used in Australia on these crops at the same rate as they are used overseas for SWD control, making this a potential gap in Australia's preparedness for SWD. It should be noted that many of the recommended actives are non-selective and can interrupt IPM systems. Further research into "softer" chemistries for SWD control in Australia is required to fit into existing crop management practices.

5.2.2 Cultural control aspects

5.2.2.1 Exclusion netting

Exclusion netting has been shown to be effective at reducing and delaying SWD infection (Leach et al. 2016, Rogers et al. 2016). The netting grade must be at least 80 grams according to Sial et al. (2017), although SWD can infest fruit even if small openings are present. Nets need to be installed before the fruits begin to ripen to prevent any SWD being trapped inside the nets. Cormier and colleagues (2015) found nets over blueberry fields had no significant effect on sugar content, yield and damage from other pests. Blueberries harvested inside the nets were significantly larger than blueberries from control plots which had no treatments applied. A larger study in raspberries investigated research plantings with insecticide and exclusion treatments (Leach et al. 2016). Each of the two control approaches provided significant reduction of infestation in raspberry fruit, but the combination treatment had the lowest overall abundance of larvae in fruit. The combination treatment also delayed the first detected larval infestation by 10 days compared to the untreated plots. Exclusion netting applied to commercial size high tunnels resulted in a significant reduction in overall SWD infestation in raspberries, as well as a 3-wk delay in the average first detectable fruit infestation. Importantly raspberry size and quality were not affected by the exclusion treatments, indicating that this approach can be an important component of growers' response to invasion by SWD in temperate climates.

While the fine mesh netting would block air flow, it also provides shading, which may be responsible for the similarity in temperature between the high net tunnels and no tunnels (Leach et al. 2016). However, the presence of the netting has the potential to increase the ambient temperature, especially in the later parts of the growing season or in warmer production regions. Extreme temperatures in netted high tunnels is a concern that should be kept in mind for fruit production in regions with different climates. However, there are fan systems and venting options that can be used to minimize the risk of extreme temperatures in high tunnels. Exclusion netting and screening can have additional pest management benefits by acting as a barrier against other pests including insects and birds. Not all pests can be managed by netting for example raspberry aphids and raspberry beetles were relatively unaffected by netting, perhaps because they were already established in plantings (Leach et al. 2016). The cost and potential for intensive labour for installation and maintenance are concerns for growers (Rogers et al. 2016). It is therefore likely that high netted tunnels are a suitable option for small-acreage and organic production systems but not necessarily for large scale set ups.

5.2.2.2 Mass trapping

For mass trapping, placing 24–40 traps per hectare (60–100 traps per acre) reduced SWD field populations in China. While this labour-intensive approach would not be possible for most growers, it could provide a non-pesticide alternative for homeowners or small-acreage farms

5.2.2.3 Cultivar selection

SWD populations are lower early in the growing season. Planting regionally appropriate, early-ripening varieties can therefore help decrease the chances of heavy infestations (Sial et al. 2018). Fruit varieties with thicker skins may also be beneficial when selecting fruit cultivars.

5.2.2.4 Harvest frequency

Leach et al. (2018) has shown how more regular picking can reduce the presence of eggs and larvae. In a study assessing the impact of raspberry harvest frequency on egg and larvae presence it was found that harvesting every day had the largest effect on egg and larvae presence. However, harvesting every two days also gave good protection from egg lay and yield was higher, possible due to the extra day allowing fruit to gain weight after reaching the required quality for market. When picking was conducted every three days there was a noticeable difference in egg and larvae presence.

5.2.2.5 Humidity control

As viability of SWD eggs is lower under dry, warm conditions (Burrack et al. 2014), cool humid microhabitats should be avoided by pruning to open up the canopy and using wider tree spacing to increase airflow to the canopy and reduce shading (Sial et al. 2018). Thinning the canopy will enhance spray coverage of insecticides when they are applied (McGinnis et al. 2018). Heavier pruning may even result in larger berries that ripen earlier in the season (Sial et al. 2018).

5.2.2.6 Field management and hygiene

There are several; field management tools and farm hygiene practices that reduce infestation levels. Studies suggest that using black plastic weed barrier as a mulch on the ground provides an effective barrier that prevents larvae from pupating underneath the soil surface, reducing SWD survival (Sial et al. 2018). The plastic barrier also helps with weed management and water retention. The use of mulches reducing standing water can further contribute to the reduction of humidity in fruit orchards (Hoashi-Erhardt and Bixby-Brosi 2014). Recommended hygiene practices to prevent or reduce the probability of SWD include

- Adopt best-practice property hygiene procedures to retard the spread of the pest between fields and adjacent properties
- Removal and treatment of fruit waste, which may harbour SWD, is a key step in preventing reinfestation of fruit production (see section 5.2.2.7 for decontamination protocols)
- Managing irrigation to avoid fruit splitting and reduce humidity
- Manage canopy
- Harvest fruit every 2-3 days - for soft fruit
- Immediate cold storage of fruit
- Alternative plant hosts present on the edge of the field should be removed to decrease the onset and severity of SWD in your crop (Sial et al. 2018).

5.2.2.7 Decontamination protocols

It is important that waste or unmarketable fruit is disposed of correctly. Many farms have their pickers use two buckets, one for marketable fruit and another for waste fruit that are disposed of to reduce the SWD population (Sial et al. 2018). Bagging is often the best method for SWD management and destruction as flies can emerge from unbagged infested fruit. An effective disposal method is to put infested fruit in clear bags sealed and left in the sun for more than 32 hours (Rufus Isaacs, personal communication). This will ensure the larvae are exposed for long enough to the lethal temperate (30°C). Burying fruit is not effective, as SWD adults find their way to the surface (Dreves AJ, unpublished data). In-field sanitation to limit the amount of fruit on the ground is also critical for mitigating SWD populations

Other decontamination included chilling, prior storage of infested cherries at −1.6–2.2°C/36°F for 96 h caused 100% mortality of eggs and neonate larvae in Japan.

5.2.3 Biological control

Given legitimate concerns over the risks and limitations of using a chemical control method, research efforts have focused on the development of environmentally sound and sustainable methods. There is a wide variety of biocontrol agents including fungi, bacteria, viruses and natural enemies of the pest that could be employed in the control programs for SWD.

Natural enemies including pathogens, predators and parasitoids can be specialists or generalists, and they can induce a high level of mortality in their hosts (Flint and Dreistadt 1998). Biological control approaches based on arthropod natural enemies are currently studied and developed worldwide. The pathogens and insects discussed below are some of the more promising biocontrols that might be applicable in an Australian setting for use when SWD establishes in Australia. More research is required, and a government process would have to be followed before the biocontrols are actively used in Australia. This could be done as part of preparedness activities for SWD.

5.2.3.1 Bacteria

Photorhabdus luminescens, a member of the Gammaproteobacteria, is a Gram-negative and mutualistic bacterium that lives in the gut of entomopathogenic nematodes belonging to the Heterorhabditidae family (Shawer et al. 2018a). Both *P. luminescens* alone and its symbiotic *Heterorhabditis* spp. nematodes are known to be highly pathogenic to insects. Once the nematode infects an insect, *P. luminescens* is rapidly released into the haemocoel, where it secretes enzymes and high-molecular-weight toxin complexes (Tc) that disintegrate and bioconvert the body of the infected insect into nutrients, which can be consumed by both the nematode and bacterium. Shaw et al (2018) investigated the possible use of *P. luminescens* to control SWD larvae and pupae. The bacterium caused a high mortality of pre-imaginal stages (mortality ranging between 86.7 % - 100 % in larvae and 43.3 % - 63.3 % in pupae) through both oral and contact toxicity. A single bacterial application may maintain a sufficiently high population on fruit for at least 5 days making it an economic control method.

Entomopathogenic bacteria can be used as stand-alone products for pest management in organic farming, their use in rotation or combination with chemical control is strongly encouraged to achieve full efficacy and eco-sustainability. This work shows that *P. luminescens* is a promising tool for the containment of SWD population. However, for its technological application in open field conditions, further studies are needed to assess the efficacy and formulation stability of products based on bacterial suspensions in different crops and environmental conditions.

5.2.3.2 Drosophila melanogaster

In Canada and the United Kingdom SWD and *Drosophila melanogaster* coexist with different but overlapping resource use in the field (Dancau et al. 2017, Shaw et al. 2018). When forced to completely or partially share resources in the laboratory *D. melanogaster* outcompetes SWD however, this is unsubstantiated in the field. Limiting SWD numbers through interspecies competition may eventually be an exploitable method of biocontrol in the field used in combination with other pest management approaches.

5.2.3.3 Nematodes and predators

Some reports of SWD within the United Kingdom indicated that population levels had remained low in the United Kingdom with no widespread reports of damage (Cuthbertson and Audsley 2016). This paper investigated several fungi and nematode biological agents to assess their ability to reduce population numbers of SWD. Both the fungus *Isaria fumosorosea* and the entomopathogenic nematode *Heterorhabditis bacteriophora* offer much potential to be incorporated into control strategies to be employed against SWD following the laboratory study that found they significantly reduced SWD levels (Cuthbertson and Audsley, 2016).

A subsequent study by Hübner et al. (2017) was performed on entomopathogenic nematodes examining their ability to infect larvae and pupae of SWD within directly sprayed fruit, fruit placed on soil, and soil. *Steinernema feltiae* and *Steinernema carpocapsae* were more efficient at infecting soil-pupating host larvae than *H. bacteriophora*. Applied as a soil drench, *S. feltiae* and *S. carpocapsae* were able to infect SWD larvae in the soil as well as hidden inside fruit. Direct application of entomopathogenic nematodes on the fruit was less successful, although emergence of flies was significantly reduced.

Another recent study found, *Orius insidiosus* (insidious flower bug) plus *Heterorhabditis bacteriophora (*neamatode*)*, resulted in an 81% reduction in blueberries and a 60% reduction in strawberries (Renkema and Cuthbertson 2018). It was not as effective in strawberry, likely due to drier substrate conditions. These results were not consistent with the study of Woltz et al. (2015), which found that *H. bacteriophora* had low infection rates while the predator *O. insidiosus* decreased SWD survival in simple laboratory arenas but not on potted blueberries or bagged blueberry branches outdoors. The use of *O. insidiosus* and *H. bacteriophora* as natural enemies may therefore have a limited success rate.

Although entomopathogenic nematodes should be easily incorporated into existing invertebrate control programmes individually, they are unlikely to control/eradicate populations. Multiple combinations of *O. insidiosus* with other agents (parasitoids, fungal entomopathogens) should be tested.

5.2.3.4 Parasitoids

Parasitoid species are insects attacking other arthropods in the egg, larval or pupal development stages. Various *Drosophila* species are subjected to strong selective pressures by egg, larval and pupal parasitoids which play a key role in their population suppression. Most studies agree that *Drosophila* parasitoids induce a high rate of mortality on their host populations although the level of parasitism varies with breeding sites, local conditions and seasons (Nikolouli et al. 2018). Studies on natural parasitoid enemies of SWD in its invaded regions have shown that parasitism rates are limited, and thus their use is not efficient for population suppression. This is attributed to the fact that SWD exhibits a high level of resistance to the majority of the larval parasitoids tested, associated to a highly efficient cellular immune system and production of a constitutively high hemocyte level.

Two main native parasitic wasp species are known to attack SWD pupae in the United States;

Pachycrepoideus vindemiae and *Trichopria Drosophilae* (Rufus Isaacs, personal communication). They were found in laboratory and field studies to successfully reproduce on SWD pupae (Gabarra et al. 2015, Stacconi et al. 2015). In California, the highest parasitism was found in non-crop plants that are refuges for SWD (e.g. cactus fruits, blackberry in riparian zones and figs and loquat). Release of these parasitic wasps in commercial cropping situations may help manage SWD.

Optimized timing of parasitoid release is essential for biological control of any parasitoid. Using a mathematical model Pfab et al. (2018) found that based on the climate of the province of Trento (northern Italy) the optimal time of *Trichopria Drosophilae* release is estimated to lie between late spring and early summer. These timings would also be consistent in Australia with SWD infestation predicted to peak in summer (dos Santos et al. 2017). Mathematical modelling has predicted that a single, optimally timed, parasitoid release event can be more effective than multiple releases over a prolonged period, but multiple releases are more robust to suboptimal timing choices (Pfab et al. 2018).

Progressively, government regulations require the development of host-specialised biological control agents. Extensive field studies and detailed evaluations are required to identify a novel strategy based on introduction and establishment of natural enemies of SWD from its native range for a long-term control and determine their effectiveness and safety with regard to non-target species. A petition is currently in revision to release SWD parasitoid wasps from China into the United States

In Europe testing on larval parasitoids from SWD's native Asia occurred on three Asian larval parasitoids and *Asobara japonica, Leptopilina japonica,* and *Ganaspis* cf. *brasiliensis*, and one European species, *Leptopilina heterotoma* (Girod et al. 2018). *Ganaspis* cf. *brasiliensis* had the highest level of specificity but variations occurred between two geographical populations tested. A Japanese population was strictly specific to SWD, whereas another population from China parasitized SWD, *D. melanogaster* and sporadically *D. subobscura*. These results show that more studies are needed on *G.* cf. *brasiliensis's* taxonomic status and the existence of biotypes or cryptic species varying in their specificity before field releases can be conducted in Europe and by extension, Australia.

5.2.4 Other control measures

5.2.4.1 Incompatible Insect Technique (IIT)

Wolbachia bacteria are naturally present in many insects and often induce a form of conditional sterility called cytoplasmic incompatibility (CI): the offspring of infected males die, unless the eggs are rescued by the compatible infection, inherited from the mother that protects the embryo (Cattel et al. 2018, Nikolouli et al. 2020). A long-recognized strategy called the incompatible insect technique (IIT) makes use of the CI phenotype to control insect populations through the mass release of infected males. One of the main points of IIT is that, contrary to SIT that allows both sexes to be released as long as they are sterile, this is not possible for IIT which requires strict male release (Nikolouli et al. 2018). Indeed, the accidental release of females infected by Wolbachia may result in the replacement of the targeted population by a population carrying the Wolbachia infection. Providing that IIT produced females are compatible with the wild males, the success of IIT could be compromised, since the Wolbachia-infected females would be compatible with either the wild or the released males.

To implement IIT in SWD, back and forth *Wolbachia* transfers between SWD and *Drosophila simulans* were used to identify *Wolbachia* strains that sterilize SWD females (Cattel et.al. 2018). Two *Wolbachia* strains were identified as potential candidates for developing IIT in SWD. Importantly the fitness or the mating competitiveness of the sterilized males was not compromised in this study. While a promising control option for SWD several critical steps still need to be tested and developed outside the laboratory before the incompatible insect technique can be used to control SWD in a large scale operational program.

5.2.4.2 Sterile Insect Technique (SIT)

The sterile insect technique (SIT) is a species-specific and environment-friendly method of pest population suppression or eradication. The method is based on the sterilization of males (although releases of both sterile males and females have been successfully used), mainly using ionizing radiation which causes dominant lethal mutations in the sperm. A sufficient number of sterile males to create an overflow ratio over a period of time are released, and they are expected to compete with wild males and mate with wild females (Dyck et al. 2006). Mating results in infertile eggs and the developing zygotes die during early embryogenesis, thus inducing sterility in the wild females. Therefore, over time, the target population declines or it is potentially eradicated.

Apart from being an environmentally sound biological control approach, SIT can be easily integrated with other biological control strategies (parasitoids, predators and pathogens). It is a species-specific method, and the release can be performed from the air thus overcoming any topography limitations. Successful development and application of an SIT operational program depends on: (a) the target population being at low levels; (b) extensive knowledge on the genetics, biology and ecology of the target pest being available before the application; (c) mass-rearing facilities being available and capable of providing large numbers of high-quality sterile insects; (d) a release technology having been developed, and the sterile individuals being efficiently monitored; (e) the releases being applied on an area-wide basis covering the whole pest population and (f) the released sterile individuals not causing any side effects on humans or the environment. The majority of the SIT programs have been applied for the control of fruit fly species as they represent one of the major insect groups of economic importance (FAO/IAEA 2013, https://nucleus.iaea.org/sites/naipc/dirsit/)

First results show X-ray radiation can inhibit the development of all stages (egg, larva, pupa and adult) of SWD and induce adult sterility (Follett et al. 2014, Kim et al. 2016). Further, radiation biology has identified a potential target dose and rearing methods are under development(Lanouette et al. 2017, Sassù et al. 2019a, Sassù et al. 2019b, Aceituno-Medina et al. 2020) Nevertheless, there are some reasonable concerns about the feasibility of SIT for this pest considering its high fecundity and the recurrent immigration of flies into the crop that are not completely confined. The short generation time of SWD indicates that SIT management should be intensive, otherwise there is a risk that the population will recover rapidly. In addition, control of large field populations of SWD poses an extra challenge for SIT. Nikolouli et al. (2018) recommend greenhouses and other confined locations, e.g. exclusion netting high tunnels, as the ideal environment for the biocontrol of SWD by using the SIT. Recent studies on plastic- and mesh-covered tunnels have shown that SWD populations are significantly decreased in these confined areas, not only due to their physical exclusion, but also because of the unfavourable microclimate that is created in these locations (Rogers *et al.* 2016). Although complete exclusion is not achievable solely by this technique, its combination with SIT could increase the biocontrol levels of SWD, thus limiting the use of insecticides. An additional challenge is that an adequate sexing system is not available for SWD, and this means that both males and females will be included in the mass-reared and released flies. Bisexual SIT has been successfully used in the past; however, male only releases have been shown to be by far more cost effective and efficient.

5.2.4.3 Combination SIT/IIT

A promising alternative approach for the biological control of SWD is coupling SIT with IIT (Nikolouli et al. 2020). In general, female insects are more sensitive to radiation than male insects in terms of the induction of sterility. The minimum dose of irradiation to induce full female sterility can be achieved at 75 Gy while an adequate level of male sterility (99.67%) was obtained at 200 Gy (Krüger et al. 2018). As a result, any accidentally released Wolbachia-infected females will be sterile and the risk of population replacement is reduced. In such a system, the released cytoplasmically incompatible males could also receive a low dose of radiation to ensure complete sterility of females that were not removed (Nikolouli et al. 2018). In this case, the sterility of released males would be due to both Wolbachia and irradiation, while the female sterility would only be caused by irradiation. This combined strategy could in principle be applied to any targeted species for which an adequate sexing system is not available. Integration of such a protocol combining low irradiation dose with CI has proved to be an efficient strategy in programs targeting the population suppression of *Aedes albopictus* (Nikolouli et al. 2018).

Before the application of a SIT and/or IIT program against SWD, it is, nevertheless important to consider potential limiting factors that may render the program ineffective. An artificial larval and adult diet along with the factors affecting mass-rearing, like ensuring biological quality and consistency in captive populations, are considerations that need to be developed. SIT and IIT are therefore not ready for use in Australia as a control method if SWD was to enter Australia today. SIT and/or IIT may however be a viable control method in the future pending successful outcomes to the hurdles listed above.

5.2.5 Post-Harvest treatment

Post incursion and establishment there are opportunities for post harvest treatment to limit the spread of SWD into pest free areas. Currently there are domestic controls within Interstate Certification Assurance (ICA) arrangements that will also be useful for minimising the spread of SWD. For example ICA 4 Fumigating with methyl bromide, ICA 7 Cold treatment and ICA 55 Irradiation treatment are in place for other pests such as Fruit fly which could be effective for SWD. Further work will be required to determine required post harvest treatments for domestic movement of infected fruit. A full review of all ICAs and investigation to confirm the usefulness and efficacy in managing infestation of fruit by SWD will be required.

5.2.1 Extension and communication

Early detection of SWD will be important in ensuring that growers can implement effective management plans quickly. To achieve this, pro-actively raising the level of knowledge about this exotic pest within affected industries will be important. Fortunately, there are many resources produced overseas, as well as expertise on communication messages, that may be accessed to aid capacity building within the supply chains of Australian industries potentially impacted by SWD.

Awareness amongst growers, supply chain and government has been shown to be vital to the management of SWD overseas. In the UK experience, proactively raising the level of knowledge about SWD within affected industries was described as important in ensuring that growers had pre-emptively employed strict hygiene measures on-farm and could quickly implement further management tactics once the pest was detected. Modelling work conducted by **cesar** indicates that there is a correlation between time passing since initial detection and reductions in crop losses. This relationship can be attributed to improved knowledge of SWD management and identification over time. Despite initial extension and communication efforts undertaken during this project there is an ongoing need to continue with awareness raising and training to increase in the chance of early detection, and to support industry in effectively managing SWD as quickly as possible if eradication cannot be achieved.

As this document has emphasised, urban environments surrounding high traffic ports-of-entry are high risk zones for SWD entry and establishment. These environments would also provide a launching point for long-range transmission around Australia, as demonstrated by modelling undertaken during this project. Awareness campaigns targeted at urban and peri-urban environments is an activity gap and should be investigated further.

In the event of a SWD incursion, clear messages about identification, impact and control will be important for facilitating an effective response or transition to management. Consultation with affected industries overseas also emphasises the important of careful handling of media messaging following an incursion in order to limit negative consumer perceptions in regard to fruit quality.

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8 APPENDICES

Appendix 1: Hosts of Spotted wing Drosophila

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Actinidiaceae	*Actinidia arguta*	hardy kiwi	secondary	field collected	field collections, but fruit are harvested hard	Lee et al 2015
Actinidiaceae	*Actinidia chinensis*	Chinese gooseberries	secondary	field collected	natural infestation	Kenis et al 2016
Adoxaceae	*Sambucus nigra spp. cerulea*	blue elderberry	wild non crop	field collected		Acheamphong 2011, Lee et al 2015
Adoxaceae	*Sambucus ebulus*	dwarf elder	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Poyet et al 2015
Adoxaceae	*Sambucus nigra*	black elder, European elder	wild non crop	Lab and field	natural infestation	Arno et al 2016, Kenis et al 2016, Grassi et al. 2011, Lee et al 2015
Adoxaceae	*Sambucus racemosa*	Red Elderberry	wild non crop	field collected	natural infestation	Kenis et al 2016, Lee et al 2015
Adoxaceae	*Viburnum dolatatum*	Linden viburnum	wild non crop	fallen fruit	reared from fallen fruit only	Mitsui et al. 2010
Adoxaceae	*Viburnum lantana*	wayfaring tree	wild non crop	field collected	natural infestation	Kenis et al 2016
Adoxaceae	*Viburnum rhytidophyllum*	Leatherleaf viburnum	wild non crop	field collected	natural infestation	Kenis et al 2016
Araceae	*Arum italicum*	Italian lily	wild non crop	field collected	natural infestation	Kenis et al 2016
Berberidaceae	*Mahonia aquifolium*	Oregon grape	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Lee et al 2015. Poyet et al 2015
Berberidaceae	*Mahonia sp.*		wild non crop	field collected	natural infestation	Kenis et al 2016
Buxaceae	*Sarcococca confusa*	Sweet box	wild non crop	Lab and field	natural infestation	Lee et al 2015
Buxaceae	*Sarcococca hookeriana*	Himalayan sweet box	wild non crop			Brewer et al 2012
Caprifoliaceae	*Lonicera alpigena*	alpine honeysuckle	wild non crop	field collected	natural infestation	Kenis et al 2016

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Caprifoliaceae	*Lonicera caerulea*	blue honeysuckle	wild non crop	field collected	natural infestation	Kenis et al 2016, Lee et al 2015
Caprifoliaceae	*Lonicera caprifolium*	Honeysuckle	wild non crop	field collected	natural infestation	Kenis et al 2016
Caprifoliaceae	*Lonicera ferdinandii*	korean honeysuckle	wild non crop	field collected	natural infestation	Kenis et al 2016
Caprifoliaceae	*Lonicera japonica*	Japanese honeysuckle	wild non crop	not reported		Dreves and Langelloto-Rhodaback (2011).
Caprifoliaceae	*Lonicera nigra*	black-berried honeysuckle	wild non crop	field collected	natural infestation	Kenis et al 2016
Caprifoliaceae	*Lonicera sp*		wild non crop	field collected	natural infestation	Kenis et al 2016, Grassi et al. 2011
Caprifoliaceae	*Lonicera xylosteum*	fly honeysuckle	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Poyet et al 2015
Caprifoliaceae	*Symphoricarpos albus*	Common snowberry	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Lee et al 2015, Poyet et al 2015
Caprifoliaceae	*Symphoricarpos spp.*	snowberry	wild non crop			Dreves and Langelloto-Rhodaback (2011).
Cornaceae	*Alangium platanifolium*	alagium	wild non crop	field collected		Mitsui et al. 2010
Cornaceae	*Aucuba japonica*	Japanese aucuba	secondary	Lab and field		Mitsui et al. 2010, Poyet et al 2015
Cornaceae	*Cornus alba*	white dogwood	wild non crop	field collected	natural infestation	Kenis et al 2016
Cornaceae	*Cornus amomum*	silky dogwood	wild non crop	field collected	natural infestation	Lee et al 2015
Cornaceae	*Cornus controversa*	Giant dogwood	wild non crop	field collected		Mitsui et al. 2010
Cornaceae	*Cornus foemina*	stiff dogwood	wild non crop	field collected	natural infestation	Lee et al 2015
Cornaceae	*Cornus kousa*	Japanese dogwood	wild non crop	field collected	natural infestation	Kenis et al 2016, Mitsui et al. 2010, Lee et al 2015
Cornaceae	*Cornus mas*	Cornelian cherry	wild non crop	field collected	natural infestation	Kenis et al 2016

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Cornaceae	*Cornus racemorse*	grey dogwood	wild non crop	field collected		Lee et al 2015
Cornaceae	*Cornus sanguinea*	common dogwood	wild non crop	field collected	natural infestation	Kenis et al 2016
Cornaceae	*Cornus sericea*	red-twig dogwood	wild non crop	Lab and field	natural infestation	Lee et al 2015, Poyet et al 2015
Cucurbitaceae	*Bryonia cretica*		wild non crop	lab reared undamaged	SWD able to complete development in artificially infested undamaged fruit.	Arno et al 2016
Dioscoreaceae	*Tamus communis*	black bryony	wild non crop	field collected	natural infestation	Kenis et al 2016
Ebenaceae	*Diospyros kaki*	persimmon	secondary	field and damaged	adults only emerging from damaged/split fruit	Kanzawa 1935, 1939,Mitsui et al. 2010
Ebenaceae	*Diospyros virginiana*	American persimmon	secondary	field collected	backyard fruit only	Maier 2012
Elaeagnaceae	*Elaeagnus multiflora*	Cherry silverberry	secondary	field collected		Kanzawa 1939, Sasaki and Sato 1995
Elaeagnaceae	*Elaeagnus umbellata*	Autumn olive	wild non crop	field collected	natural infestation	Lee et al 2015
Elaeagnaceae	*Hippophae rhamnoides*	sea buckthorn	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Poyet et al 2015
Elaegnaceae	*Elaeagnus multiflora*	silver berry	primary	field collected		Kanzawa 1939
Elaegnaceae	*Elaeagnus umbellata*	autumn olive	wild non crop			Lee et al 2015, Maier 2012
Ericaceae	*Arbutus unedo*	Strawberry tree	secondary	Lab and field	natural infestation	Kenis et al 2016, Arno´ et al. 2012
Ericaceae	*Gaultheria adenothrix*	akamono	wild non crop	fallen fruit		Mitsui et al. 2010
Ericaceae	*Gaultheria shallon*	salal	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Lee et al 2015
Ericaceae	*Gaultheria x wisleyensis*		wild non crop	field collected	natural infestation	Kenis et al 2016
Ericaceae	*Vaccinium angustifolium*	blueberry	primary	field collected		Arakelian 2009; Dreves et al., 2009; Hauser et al., 2009;

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Ericaceae	*Vaccinium corymbosum*	blueberry	primary	field collected		Arakelian 2009; Dreves et al., 2009; Hauser et al., 2009;
Ericaceae	*Vaccinium vitis-idea*	Lingonberry	secondary	field collected	natural infestation	Kenis et al 2016. lee et al 2015
Ericaceae	*Vaccinium marcocarpon*	cranberry	secondary	damaged fruit	DAWR reports differing inforamtion on the status. Suspected as a host, but details are scant. Lab trials have apparently not observed siccessfil oviposition. Current status is highly conservative.	Steffan 2013
Ericaceae	*Vaccinium myrtilloides*	sourtop blueberry	primary	field collected	natural infestation	Kenis et al 2016
Ericaceae	*Vaccinium myrtillus*	bilberry	wild non crop	Lab and field	natural infestation and "rearing conditions" - egg laying (in lab assumedly)	Kenis et al 2016, Grassi et al. 2011
Ericaceae	*Vaccinium oldhamii*	unnamed	wild non crop	field collected	natural infestation	Kenis et al 2016
Ericaceae	*Vaccinium praestans*	Kamchatka Bilberry	wild non crop	field collected	natural infestation	Kenis et al 2016
Grossulariaceae	*Ribes spp.*	black currant, red currant	secondary	damaged fruit	Canadian records are limited to damaged fruit and no damage observed in US. Possibly only non-commerical fruit	Kenis et al 2016
Grossulariaceae	*Ribes uva-crispa*	gooseberry	primary	lab reared undamaged	Lab development has been observed, but no records of damage. However US advise is for control measures.	Lee et al 2015
Lauraceae	*Lindera benzoin*	spice bush	wild non crop	field collected	natural infestation	Lee et al 2015
Liliaceae	*Polygonatum multiflorum*	Solomon's-seal	wild non crop	field collected	natural infestation	Kenis et al 2016

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Melanthiaceae	*Paris quadrifolia*	herb-paris	wild non crop	field collected	natural infestation	Kenis et al 2016
Moraceae	*Ficus carica*	Common fig, 'Brown Turkey' and 'Mission'	secondary	field collected	natural infestation, eported as a host, but damage on on overripe fruit	Kenis et al 2016, Yu et al. 2013
Moraceae	*Maclura pomifera*	Osage orange	secondary	not reported		Dreves and Langelloto-Rhodaback (2011).
Moraceae	*Morus alba*	White mulberry	secondary	field collected		Kanzawa 1939
Moraceae	*Morus indica*	silkworm mulberry	secondary	fallen fruit	however noted that other species are very good hosts	Mitsui et al. 2010
Moraceae	*Morus nigra*	Black mulberry	secondary	field collected	natural infestation	Lee et al 2015
Moraceae	*Morus alba x rubra*	'Illinois Everbearing'	secondary	field collected		Yu et al. 2013
Moraceae	*Morus rubra*	red mulberry	secondary	field collected	host - need to examine details	Plant Inspection Advisory 2010
Moraceae	*Morus sp*	Mulberry	secondary			Kanzawa 1935, Sasaki and Sato 1995
Musaceae	*Musa acuminata*	banana	secondary	damaged fruit	overripe fruits only	Price and Nagle 2009
Myricaceae	*Morella rubra*	Chinese bayberry	primary		host - no further detail	Yukinari 1988
Myrtaceae	*Eugenia uniflora*	Surinam cherry	secondary	field collected	commerical importance unclear	Plant Inspection Advisory 2010
Myrtaceae	*Psidium cattleianum*	Cattley guava	wild non crop	fallen fruit	collected from trees and on ground	Kido et al 1996
Myrtaceae	*Psidium cattleianum*	strawberry guava	wild non crop	fallen fruit	rotting fruit only	Andreazza 2017
Phytolaccaceae	*Phytolacca americana*	American pokeweed	secondary	Lab and field	natural infestation	Sasaki and Sato 1995,Lee et al 2015,Kenis et al 2016
Phytolaccaceae	*Phytolacca esculenta*		wild non crop	field collected	natural infestation	Kenis et al 2016
Rhamnaceae	*Frangula alnus*	alder buckthorn	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Grassi et al. 2011, Poyet eta al 2015

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Rhamnaceae	*Frangula purshiana*	Cascara buckthorn	wild non crop	field collected	natural infestation	Lee et al 2015
Rhamnaceae	*Rhamnus alpina*	Alpine buckthorn	wild non crop			cini et al 2012
Rhamnaceae	*Rhamnus cathartica*	common buckthorn	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosac.	*Eriobotrya japonica*	loquat	secondary	field and damaged	natural infestation	Kenis et al 2016, Plant Inspection Advisory 2010, Kanzawa 1939
Rosaceae	*Amelanchier lamarckii*	juneberry	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Amelanchier ovalis*	snowy mespilus	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Cotoneaster franchetii*	Franchet's cotoneaster	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Cotoneaster lacteus*	Milkflower cotoneaster	wild non crop	field collected	natural infestation	Kenis et al 2016, Lee et al 2015
Rosaceae	*Cotoneaster rehderi*	Bullate cotooneaster	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Crataegus chrysocarpa*	Fireberry Hawthorn	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Crataegus monogyna*	common hawthorn	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Fragaria ananassa*	strawberry	primary	Lab and field		Arakelian 2009; Dreves et al., 2009; Hauser et al., 2009; Price & Nagle 2009
Rosaceae	*Fragaria vesca*	wild strawberry	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Poyet et al 2015
Rosaceae	*Malus baccata*	Siberian crab apple	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Malus domestica*	apple	secondary	fallen fruit		Walsh et al., 2001
Rosaceae	*Malus pumila*	Paradise apple	secondary	field and fallen	damaged only	Kanzawa 1939
Rosaceae	*Photinia beauverdiana*	Christmas berry	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Photinia prunifolia*	Black Chokeberry	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Photinia villosa*	oriental photinia	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Potentilla indica*	mock strawberry	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Lee et al 2015

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Rosaceae	*Prunus armeniaca*	Apricot	primary	field and damaged	natural infestation in Kenis et al	Kanzawa 1935, 1939, Kenis et al 2016
Rosaceae	*Prunus armeniaca x salicina*	plumcot	primary			Bolda 2009
Rosaceae	*Prunus avium*	Various ornamental and wild cherries	primary	Lab and field		Kanzawa 1939, Lee et al 2015, Kenis et al 2016
Rosaceae	*Prunus buergeriana*	shirozakura	primary	field collected		Sasaki and Sato 1995
Rosaceae	*Prunus caroliniana*	sherry laurel	secondary	field collected	adults trapped in orchard, but no reports of larvae in fruit. However listed as a host in some reports	(Triology 2009)
Rosaceae	*Prunus cerasifera*	Cherry plum	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Prunus cerasus*	sour cherry	primary	field collected	natural infestation	Kenis et al 2016,Kanzawa 1939
Rosaceae	*Prunus domestica*	plum	primary	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Prunus donarium*	wild cherry	primary	field collected		Kanzawa 1939, Mitsui et al. 2006
Rosaceae	*Prunus japonica*	Korean cherry	primary	field and fallen		Kanzawa 1935, 1939
Rosaceae	*Prunus laurocerasus*	Cherry laurel	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Lee et al 2015
Rosaceae	*Prunus lusitanica*	Portuguese-laurel	wild non crop	Lab and field	natural infestation	Kenis et al 2016,Lee et al 2015
Rosaceae	*Prunus mahaleb*	mahaleb cherry	wild non crop	Lab and field	natural infestation	Arno et al 2016, Kenis et al 2016, Kanzawa 1935, 1939
Rosaceae	*Prunus maritima*	beach plum	secondary	field collected	wild grown fruit	Meier 2012
Rosaceae	*Prunus mume*	Asian plum, Japanese apricot	primary			Hauser & Damus 2009
Rosaceae	*Prunus nipponica*	Japanese alpine cherry	wild non crop	fallen fruit		Mitsui et al. 2010
Rosaceae	*Prunus padus*	bird cherry	wild non crop	field collected	natural infestation	Kenis et al 2016

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Rosaceae	*Prunus persica*	peach	primary	damaged fruit		Kanzawa 1935, 1939, Sasaki and Sato 1995
Rosaceae	*Prunus persica va. Nucipersica*	nectarine	primary			Kanzawa 1939, Dreves et al., 2009; Hauser et al., 2009;
Rosaceae	*Prunus salicina*	Japanese plum	primary	damaged fruit		Kanzawa 1935, 1939
Rosaceae	*Prunus sargentii*	Sargents cherry	primary	field collected		Kanzawa 1935
Rosaceae	*Prunus serotina*	black cherry	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Poyet et al. 2014, 2015
Rosaceae	*Prunus serrulata*	Japanese mountain cherry	primary	field collected		Sasaki & Sato 1995
Rosaceae	*Prunus spinosa*	blackthorn	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Prunus virginiana*	choke cherry	primary	field collected		Lee et al 2015
Rosaceae	*Prunus yedoensis*	Tokyo cherry	primary	field collected		Kanzawa 1935, 1939, Sasaki and Sato 1995
Rosaceae	*Prunus cerasus*	dwarf cherry	primary			Seljiak, 2011
Rosaceae	*Pyracantha sp.*		wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Pyrus communis*	pear	secondary	damaged fruit		Benito and Lopes-da-silva 2016
Rosaceae	*Pyrus pyrifolia*	Asian pear, nashi pear	secondary	damaged fruit		Dreves et al., 2009;
Rosaceae	*Ribes rubrum*	Redcurrant	secondary	Lab and field	natural infestation	Kenis et al 2016, Poyet et al. 2015
Rosaceae	*Ribes sanguineum*	redflower current	secondary	Lab reared		Poyet et al 2015
Rosaceae	*Rosa acicularis*	Prickly wild rose	secondary	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rosa canina*	dog rose	secondary	field collected	natural infestation and SWD able to complete development in artificially infested undamaged fruit.	Kenis et al 2016,Arno et al 2016

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Rosaceae	*Rosa glauca*	Redleaf Rose	secondary	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rosa pimpinellifolia*	burnet rose	secondary	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rosa rugosa*	wild rose, rose hips	secondary	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rubus allegheniensis*	Allegheny blackberry	primary	field collected	wild grown fruit only recorded	Lee et al 2015
Rosaceae	*Rubus armeniacus*	Himalayan blackberry	primary	Lab and field		Lee et al 2015
Rosaceae	*Rubus caesius*	European dewberry	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rubus crataegifolius*	Various wild raspberries	wild non crop	fallen fruit		Mitsui et al. 2010
Rosaceae	*Rubus fruticosus*	blackberry, marionberry	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rubus idaeus*	raspberry	primary	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rubus laciniatus*	evergreen blackberry	primary	field and fallen		cini et al 2012
Rosaceae	*Rubus loganobaccus*	boysenberry	primary	field collected		Hauser & Damus 2009
Rosaceae	*Rubus microphyllus*	wild raspberry	wild non crop	field collected		Kanzawa 1939, Mitsui et al. 2010
Rosaceae	*Rubus parvifolius*	Japanese raspberry	primary	field collected		Kanzawa 1939, Sasaki and Sato 1995
Rosaceae	*Rubus phoenicolasius*	Wineberry	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rubus saxatilis*	stone bramble	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Rubus spectabilis*	salmon berry	secondary	fallen fruit	wild grown fruit only recorded	Lee et al 2015
Rosaceae	*Rubus spectabilis*	Salmonberry	wild non crop	Lab and field	natural infestation	Lee et al 2015
Rosaceae	*Rubus ulmifolius*	elmleaf blackberry	wild non crop	field collected	natural infestation	Arno et al 2016
Rosaceae	*Rubus x loganobaccus*	loganberry	primary	field collected		
Rosaceae	*Sorbus aria*	common whitebeam	wild non crop	field collected	natural infestation	Kenis et al 2016
Rosaceae	*Sorbus aucuparia*	mountain ash	wild non crop	field collected	natural infestation	Kenis et al 2016

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Rosaceae	*Sorbus sitchensis*	western mountain ash	wild non crop	lab reared undamaged		Lee et al 2015
Rutaceae	*Citrus sinensis*	orange	secondary	fallen fruit		Walsh et al., 2001, Caprile 2016
Rutaceae	*Citrus x paradisi*	grapefruit	secondary	fallen fruit		Triology 2010, Price and Nagle 2009
Rutaceae	*Murraya paniculata*	Orange jasmine	secondary			Plant Inspection Advisory 2010
Rutaceae	*Skimmia japonica*	red skimmia	secondary	Lab reared	oviposition host - failed to develop	Lee et al 2015
Sapindaceae	*Sapindus spp.*	soapberry	secondary			Dreves and Langelloto-Rhodaback (2011).
Solanaceae	*Lycium barbarum*	goji berry	secondary	field collected	reported host, but status uncertain	Kenis et al 2016
Solanaceae	*Solanum chenopodioides*	whitetip nightshade	wild non crop	lab reared only	SWD able to complete development in artificially infested undamaged fruit.	Arno et al 2016
Solanaceae	*Solanum dulcamara*	bitter sweet nightshade	wild non crop	Lab and field	SWD able to complete development in artificially infested undamaged fruit.	Arno et al 2016,Kenis et al 2016, Lee et al 2015
Solanaceae	*Solanum lycopersicum*	Tomato	secondary	damaged fruit	ripe fruit in lab, but field reports appear limited to cut or damaged fruit. No adult development in lab studies (Lee et al 2015)	Kanzawa 1935, Plant Inspection Advisory 2010
Solanaceae	*Solanum nigrum*	black nightshade	wild non crop	field collected	natural infestation, SWD able to complete development in artificially infested undamaged fruit.	Kenis et al 2016, Arno et al 2016
Solanaceae	*Solanum villosum*	red nightshade	wild non crop	field collected		Arno´ et al. 2012

FAMILY	SCIENTIFIC NAME	COMMON NAME(S)	HOST STATUS	FOUND ON	NOTES	KEY REFERENCE(S)
Styracaceae	*Styrax japonicus*	Japanese snowbell	wild non crop	Lab reared	reports are not clear whether a host	Mitsui et al., 2010
Taxaceae	*Taxus baccata*	common yew	wild non crop	Lab and field	natural infestation	Kenis et al 2016, Poyet et al 2015
Taxaceae	*Taxus cuspidata*	Japanese yew	secondary			Maier 2012
Taxaceae	*Torreya nucifera*	Japanese torreya	wild non crop	fallen fruit		Mitsui et al. 2010
Theaceae	*Camellia japonica*	Japanese camellia	wild non crop	field collected	on flowers	Nishiharu, 1980
Thymelaeaceae	*Daphne mezereum*	mezereum	wild non crop	field collected	natural infestation	Kenis et al 2016, Tonina 2016
Vitaceae	*Ampelopsis glandulosa*	porcelain berry	secondary	field collected		Maier 2012
Vitaceae	*Parthenocissus quinquefolia*	Virginia creeper	wild non crop	field collected	natural infestation	Kenis et al 2016
Vitaceae	*Vitis labrusca*	concord grapes	primary	field collected		Kanzawa 1939, Seljak 2011
Vitaceae	*Vitis vinifera*	table grapes, wine grapes	primary	field collected	natural infestation	Kenis et al 2016, Kanzawa 1936, 1939; Dreves et al., 2009; Hauser et al., 2009

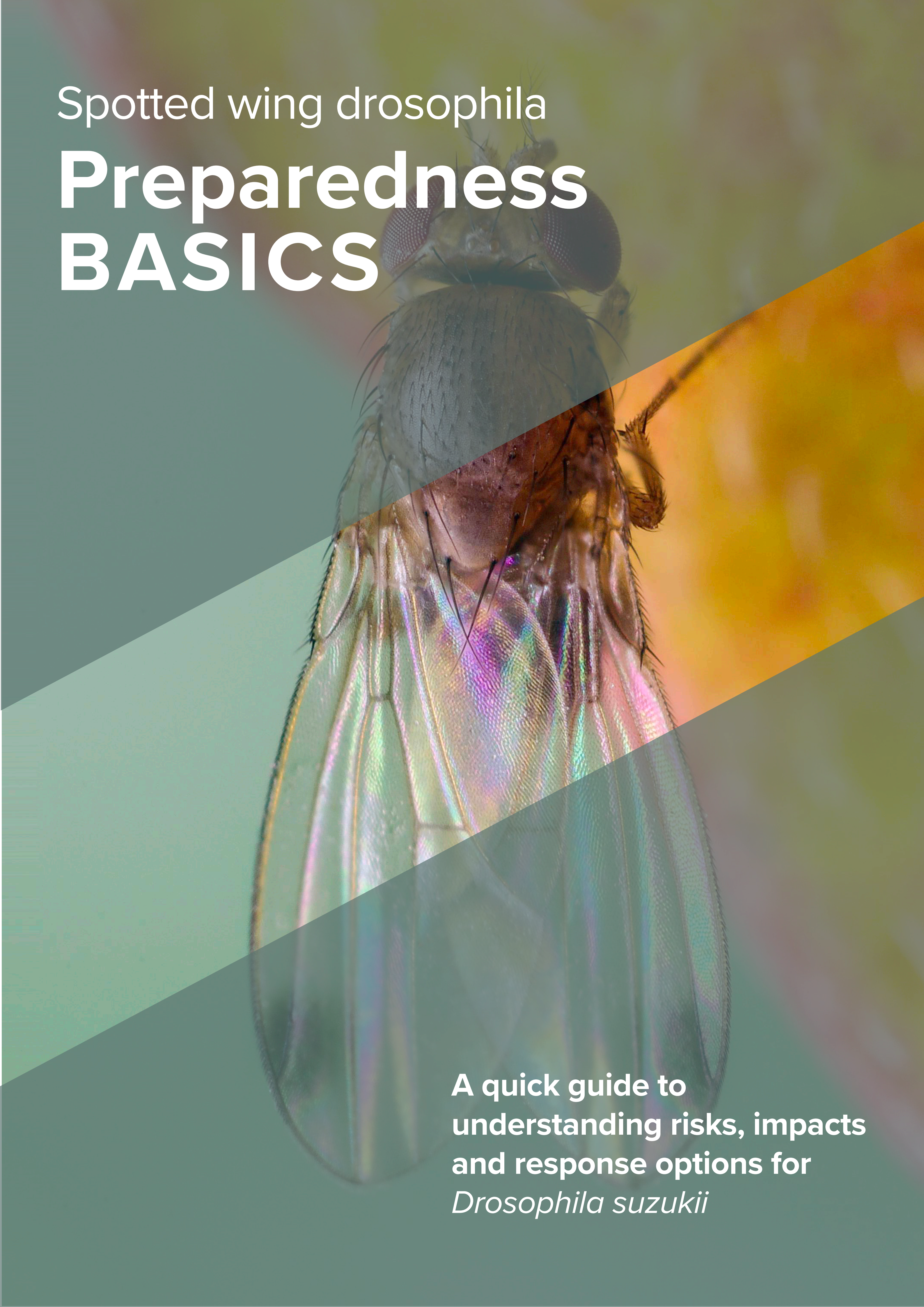
Appendix 2: First detections of SWD in countries in Europe and the Americas ordered chronologically for each region.

COUNTRY	DATE	VEGETATION OBSERVATIONS	MEANS OF DETECTION	PRIOR TRAPPING?	LAND USE	REFERENCE
North America and central America						
USA - Hawaii	1980					Hauser 2011
USA-mainland	2008	Raspberry and Strawberry	Crop scout submission		Production area	Hauser, 2011
Canada	2009					Asplen et al 2015
Mexico	2011					Lee et al 2011
Europe						
Spain	2008	Pine forest	Trapping	Yes in 2007	Wilderness area	Calabria et al 2012
Italy	2008	Raspberries	Malaise traps			Cini et al 2012, EPPO 2010
France	2009	Cherry and Strawberry				Calabria et al 2010, EPPO 2010
Slovenia	2010					Seljak 2011
Croatia	2010	Raspberry, peach and grapevine	Trapping		Production area	Bjelis et al 2015
Germany	2011		Trapping	Yes in 2010		Vogt *et al.* 2012; Asplen et al 2015
Belgium	2011				private garden	Mortelmans *et al.* 2012, EPPO 2011
Austria	2011					Asplen et al 2015
Switzerland	2011	Strawberry, raspberries, blueberries and cherry orchards	Trapping (apple cider vinegar)		Production area	EPPO 2011
Portugal	2012	Raspberries			Commercial greenhouse	Asplen et al 2015; EPPO 2012
Netherlands	2012		Trapping (apple cider vinegar and wine)		Wilderness areas and private gardens	Helsen *et al.* 2013; Asplen et al 2015
United Kingdom	2012	Raspberry and blackberry			Research plots	EPPO 2012; Asplen et al 2015

COUNTRY	DATE	VEGETATION OBSERVATIONS	MEANS OF DETECTION	PRIOR TRAPPING?	LAND USE	REFERENCE
Hungary	2012		Bottle traps (apple cider vinegar)		Highway rest stop	Lengyel et al 2015
Bosnia and Herzegovina	2013					Ostojic *et al.* 2014; Asplen et al 2015
Montenegro	2013		Trapping			Radonjic and Hrncic 2015; Asplen et al 2015
Romania	2013	Blackberry	Tephri traps		Wilderness	Chireceanu et al 2015; Asplen et al 2015
Serbia	2014	Raspberry, blackberry, fig and grape	Fruit survey			Tosevski *et al.* 2014
Sweden	2014		Trapping		Urban (commercial)	Manduric 2017
Ukraine	2014			Yes, since 2005		Lavrinienko et al 2017
Turkey	2014	Strawberry	Crop observation		Research plots	Orhan et al 2016
Poland	2014	Blueberry and raspberry		Yes, 2012 & 2013	Production area	Asplen et al 2015
Greece	2014	Native vegetation	Trapping (beer)		Wilderness area	Maca 2014; Asplen et al 2015
Bulgaria	2014	Cherries	Trapping	Yes, since 2012	Production area	EPPO 2015; Asplen et al 2015
Czech Republi	2014	Fruit	Trapping (apple cider vinegar)		Production area	EPPO 2014; Asplen et al 2015
Slovakia	2014	Apple and plum	Trapping		Production area	EPPO 2014; Asplen et al 2015
Ireland	2015		Trapping		Production area	EPPO 2015
Cyprus	2016		Trapping		Production area	EPPO 2017
South America						
Brazil	2013		Trapping (banana)			Depra et al 2014; Vileia and Mori 2014
Uruguay	2013	Blueberry	Trapping, fruit surveys			Gonzales et al 2015; EPPO 2016
Argentina	2015					Lavagnino et al 2018
Chile	2017	Blackberry	Trapping			EPPO 2017

Spotted wing drosophila

Preparedness BASICS



A quick guide to understanding risks, impacts and response options for *Drosophila suzukii*

Preface

Spotted wing drosophila (*Drosophila suzukii*; SWD) is not found in Australia. However, as an exotic pest that has spread to many countries overseas it poses a serious threat to Australian fruit industries. In Australia it has been identified as a high priority exotic pest of the apple and pear, strawberry, blueberry, *Rubus* sp., cherry, dried fruit, summerfruit, table grape and wine grape industries.

Unlike most *Drosophila* species, females have the ability to infest ripening fruit. As a result, an infestation leads to impacts on fruit quality and yield. An outbreak and establishment in Australia would lead to significant pest management challenges for fruit orchards, and would require steps to be taken to limit spread through movement of host fruit.

In 2018, Hort Innovation initiated project MT17005 '*Improving the biosecurity preparedness of Australian horticulture for the exotic spotted wing drosophila (Drosophila suzukii)*'. This project was a collaboration between Plant Health Australia, **cesar**, Plant & Food Research, and Horticulture New Zealand. From May 2018 until June 2020 the project team investigated a range of topics to increase our understanding of how SWD could be detected early, contained and monitored if there were an incursion in Australia or New Zealand.

This project resulted in the development of several key outputs, including a spotted wing drosophila preparedness report, which incorporates project findings. The preparedness report was developed to aid government and industry biosecurity professionals in preparing and executing spotted wing drosophila incursion response activities and to support a transition from eradication or containment to a management scenario if needed.

SWD Preparedness Basics includes need-to-know information about this pest for government and industry biosecurity professionals and acts as your introduction to SWD and as an entry point to the preparedness report. Use it to quickly become acquainted with spotted wing drosophila during or prior to an incursion, and as a roadmap to using the preparedness report efficiently.

Preparedness Report

The spotted wing drosophila preparedness report is a detailed document that aggregates the latest knowledge about spotted wing drosophila for Australian government and industry biosecurity personnel.

Look up the preparedness report to learn more about spotted wing drosophila

Improving the biosecurity preparedness of Australian horticulture for the exotic spotted wing drosophila (2020). Plant Health Australia, Canberra, ACT. Hort Innovation project MT17005

This spotted wing drosophila Preparedness Basics guide contains extracted information from the preparedness report. It gives you the basics, while the preparedness report takes a deep dive into spotted wing drosophila research and current knowledge to assist in determining the requirements for an initial response to a detection as well as management of this species in Australia.

In this guide, references to the preparedness report are made to aid fast navigation of that document.

Keep an eye out for these signposts, which indicate where you can find more information in the preparedness report.

Refer to Preparedness Plan section 2

Pest details

Drosophila suzukii (Matsumura) is a member of the Diptera (fly) family. Like other flies, SWD is characterised by four distinct life stages: egg, larva, pupa, and adult. Immature life stages of most *Drosophila* species feed on fungi or decaying plant tissue. Spotted wing drosophila is markedly different due to a preference for laying its eggs in fruits that are not yet ripe, and for feeding of its larvae on the tissue of fresh fruit.

Lifecycle: In laboratory trials, this species has been shown to survive between 30-179 days, however, the life span of adults in the field is uncertain. After eclosion (emergence from the pupal case), adults typically become sexually mature in 1-2 days. A female can oviposit 7-16 eggs per day with several hundred eggs laid during her life. The average number of eggs laid by a female over the first four weeks of oviposition ranges from 85-148 eggs.

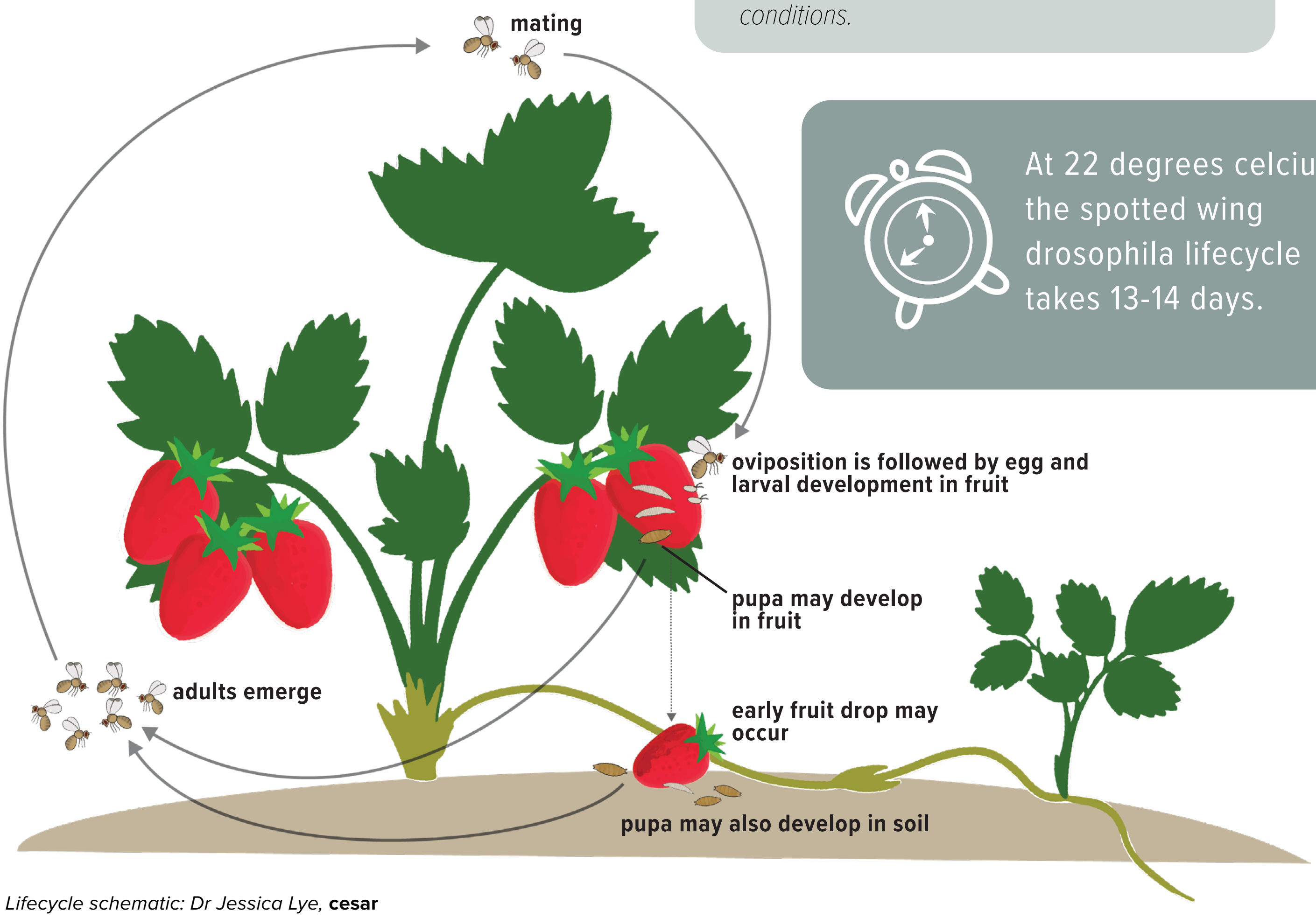
Sexually mature females enter reproductive diapause when the photoperiod is less than 14 hours at moderate temperatures (15 or 20 °C). At temperatures less than 10°C it will enter this diapause regardless of photoperiod.

Host type as well as environmental factors, such as temperature, influences the number of eggs laid. Eggs, larvae and pupae vary in developmental time depending on environmental conditions, with warm conditions leading to the shortest development times. At 22°C, the egg stage takes approximately 1.4 days, the larval stage takes 6 days, and the pupal stage takes 6 days. Therefore, under mild conditions it will take 13-14 days for this fly to develop from egg to adult. A short development time allows the fly to complete several generations across one growing season.

Once hatched larvae feed on the fruit as they develop through three instars (growth stages). If the fruit has dropped to the ground, third instar larvae will move into the soil and pupate. If fruit is still on the branch, larvae will often drop and pupate in the soil rather than remain in the fruit.

What is 'reproductive diapause'?

This is a period when physiological processes involved in reproduction are stopped or slowed down, usually due to challenging environmental conditions.



Lifecycle schematic: Dr Jessica Lye, **cesar**

At 22 degrees celcius the spotted wing drosophila lifecycle takes 13-14 days.

Common name	Spotted wing drosophila
Scientific name	*Drosophila suzukii* (Matsumura, 1931)
Synonyms	*Leucophenga suzukii* (Matsumura, 1931)
Taxonomic position	Class: Insecta Order: Diptera Family: Drosophilidae Genus: *Drosophila* Sub genus: *Sophophora*

Spotted wing drosophila adults hover around a blackberry - a preferred host for feeding and oviposition.

Refer to Preparedness Report section 2.2 for a detailed host list.

Refer to Preparedness Report section 2

Hosts: While much of the focus on spotted wing drosophila is related to its status as a serious pest of soft and thin-skinned fruits, there is evidence that this it has a wide host range. Various soft fruited crops including figs, summerfruit (apricots, nectarines, plums, peaches), cherries, strawberries, *Rubus* sp. berries (raspberries, blackberries and related crops), *Ribes* sp. berries (currents, gooseberries, etc.), blueberries, and grapes have been identified as hosts. Other thicker-skinned fruit such as citrus and pome fruit (apples and pears, kiwifruit etc.) can also act as hosts when the fruit is damaged.

In the event of an incursion, the wide host range, including many wild and ornamentally cultivated plants, would provide significant habitat for this pest in Australia outside of managed crops.

Signs and symptoms: SWD larvae cause damage by feeding on the pulp inside fruit and berries. Infested fruit show small scars and indented soft spots on the surface, which is a result of oviposition. Infested fruit can collapse around the larval feeding site causing a depression or blemish on the fruit and sap exudates may also be evident. The oviposition scar exposes the fruit to secondary attack by pathogens and other insects. If a spotted wing drosophila infestation is high, the entire fruit can collapse. Signs of infestation may be confused with normal ageing of mature fruit. However, fruit infested with SWD show rapid softening and wrinkling within a few days after egg laying. Signs and symptoms of SWD may be delayed if fruit is cold stored, with symptoms of fruit collapse developing rapidly when fruit is brought out of cold storage.

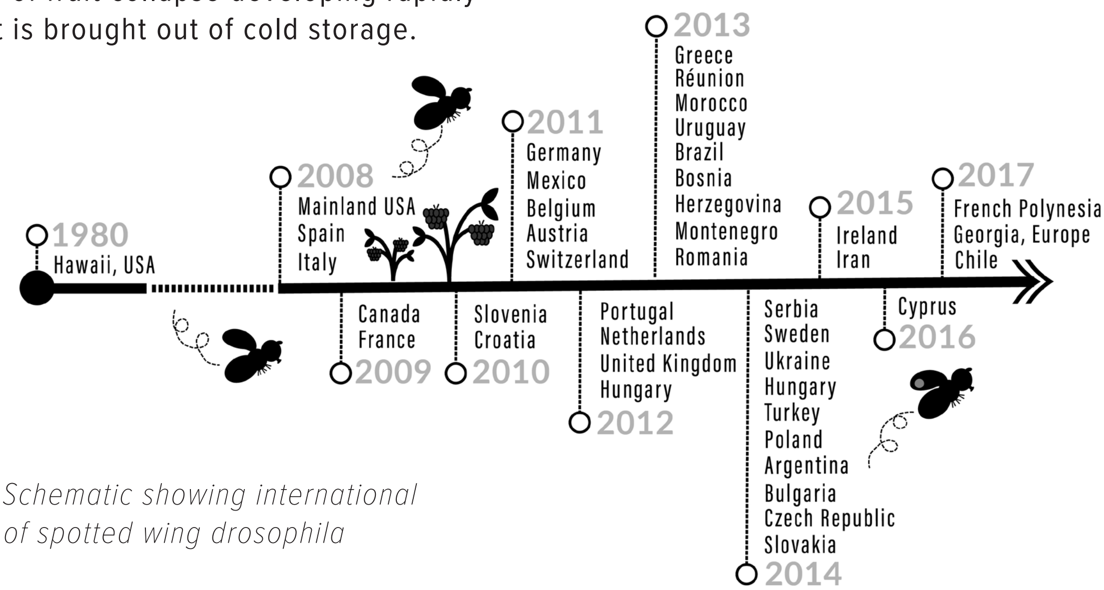
Diagnostic considerations: Adult SWD are small flies 2-3 mm in length with a wingspan of 6-8 mm. They have prominent red eyes and are pale brown or yellow-brown in colour and have dark abdominal bands. The males are generally smaller than females and have a dark spot on the end of each wing. The females can be distinguished under a microscope from other *Drosophila* species by the presence of a double serrated ovipositor.

The pupae are 1 mm wide, 2-3 mm long and red to brown in colour. They are oval shaped and have a pair of distinctive horn shaped protrusions (respiratory organs), which divide into branches at one end and a small v-shaped structure at the other (also for respiration).

Larvae are cream to white maggots, approximately 3 mm in length. Eggs are white, oval shaped, 0.6 mm in length and have two filaments at one end for respiration, which sometimes protrude from fruit after oviposition.

Superficially spotted wing drosophila is very similar to some endemic insects, with several similar *Drosophila* species common in rotten fruit in Australia. As a result, identification based on morphology of the pest will be challenging for most people.

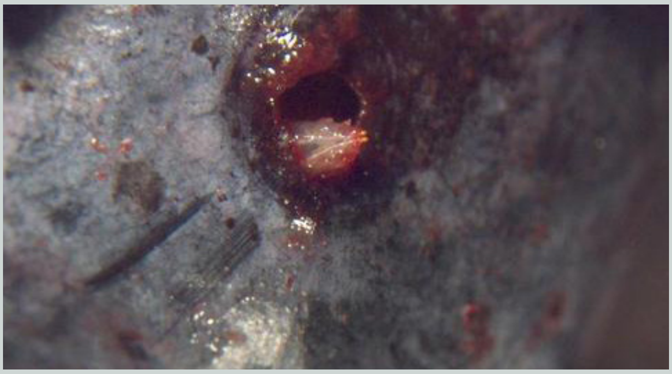
Geographic distribution: The native geographical range of spotted wing drosophila is thought to include ten countries across south-east Asia, ranging from Japan to Pakistan. Over the past decade it has spread to North America, South America and Europe.

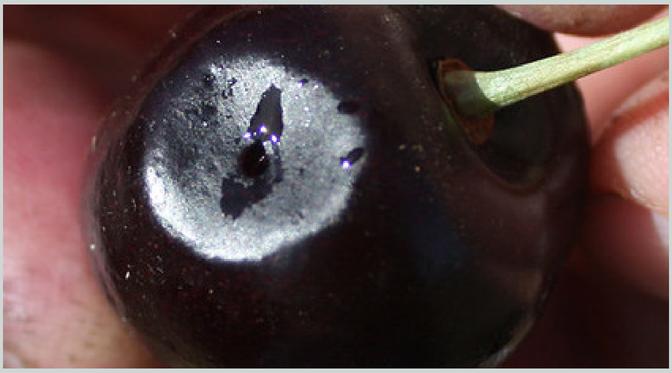


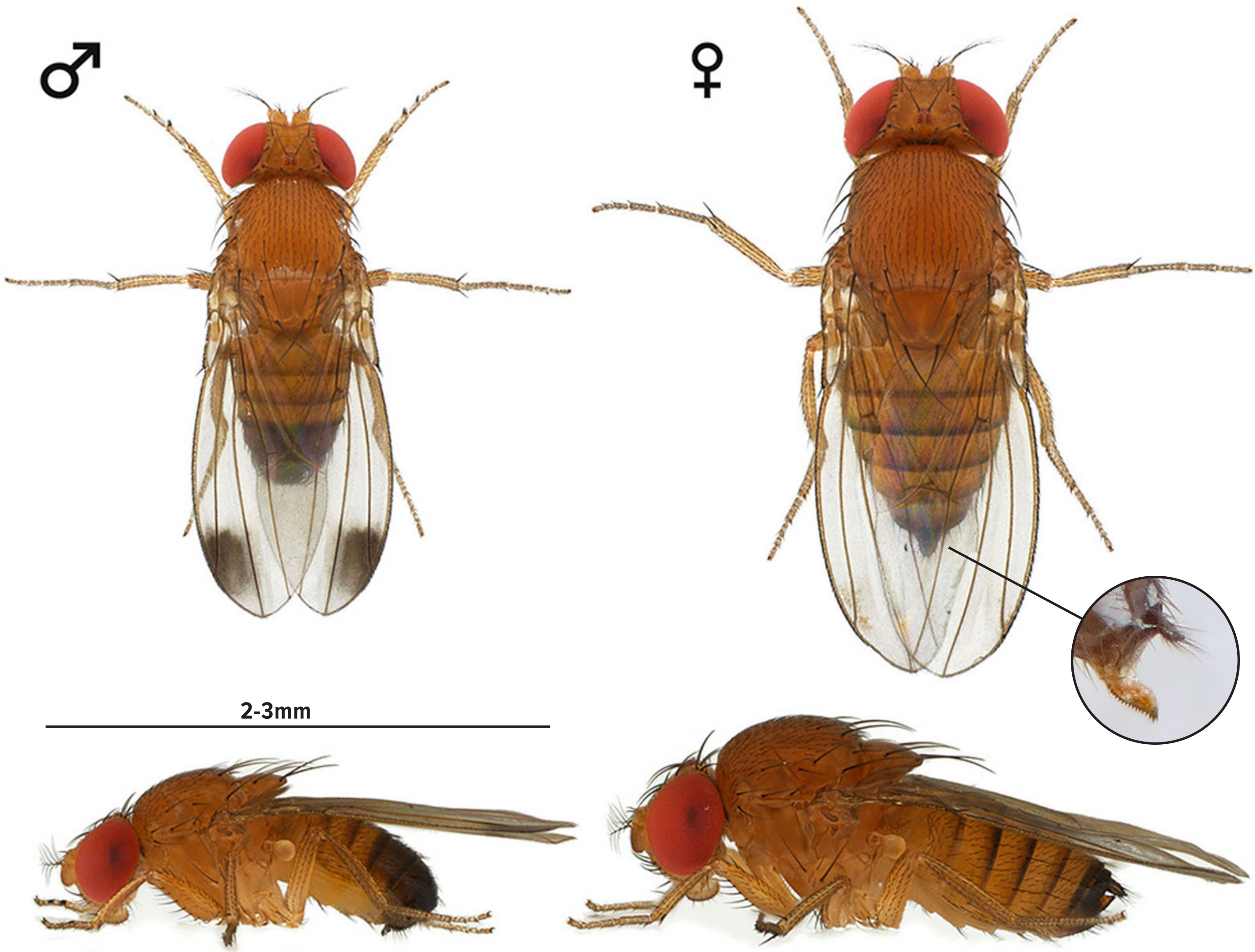
Above: Schematic showing international spread of spotted wing drosophila

Eggs, larvae and pupae can only be differentiated from closely related *Drosophila* species using molecular methods, or by rearing them into adults.

Top right: Eggs oviposited in strawberry (Hannah Burrack, North Carolina State University, Bugwood.org). Bottom right: Depression in cherry resulting from larval feeding (Oregon Dept Ag - Amy Dreves - Flickr SWD blackberry NonCommercial-NoDerivs 2.0 Generic CC BY-NC-ND 2.0). Bottom left: Larva feeding on blueberry (Frank Hale, University of Tennessee, Bugwood.Org)







Above: Spotted wing drosophila adult male (left) and female (right), dorsal and lateral views. The female serrated ovipositor is shown (circle).

Photos of adults: AgriScope [adapted], flickr.com, used under licence NonCommercial-NoDerivs 2.0 Generic CC BY-NC-ND

Photo of ovipositor: Martin Cooper [adapted], flickr.com, used under licence NonCommercial-NoDerivs 2.0 Generic CC BY-NC-ND

Spotted wing drosophila larvae feeding on wineberry.

Refer to Preparedness Report section 2.4 for detailed diagnostic information.

Refer to Preparedness Report section 3

Risk pathways

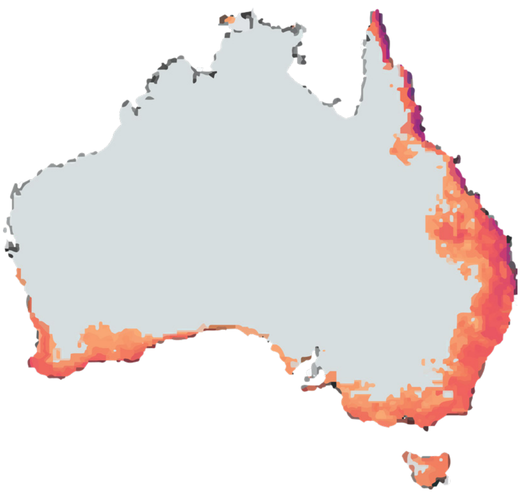
Overall it has been determined that the likelyhood of spotted wing drosophila being transported to to Australia is low due to:

- current import and phytosanitary restrictions on exporters of high-risk commodities;
- small volumes of imported fresh fruit due to limited demand;
- requirements for declaration of any plant-derived goods associated with passenger movements and mail; and
- the low likelihood of natural spread (flight) to Australia.

To further minimise risk of an incursion it is necessary to prioritise surveillance activities, based on where this pest is most likely to enter and establish.

Research group, **cesar**, have modelled establishment and spread potential of spotted wing drosophila in Australia. According to this work, a large portion of Australia's southern and eastern coastal fringe, as well as some areas in western Australia are predicted to have climates that will support establishment.

One of the most concerning attributes of SWD as a plant pest is its ability to invade a region quickly. This is largely due to high reproductive rates, relatively long life, a broad host range, and the capacity to survive in both cool and warm areas. In the absence of control activities it is predicted that the fly would fill its ecological niche in climatically suitable regions within six years of an incursion.



Above: Predicted establishment of spotted wing drosophila if the pest were to enter Australia and successfully spread. Darker colours indicate higher establishment potential. Source: Dr James Maino, **cesar**

Refer to Preparedness Report sections 3.2 and 3.3 for more information on predicted spread and establishment.

Steps to entry

For a spotted wing drosophila incursion to occur via infested fresh fruit a number of steps must take place:

1. **Infestation of fruit in currently infested range**
2. **Survival of post-harvest processes**
3. **Survival during transport**
4. **Transport to a new region or country**
5. **Development to adulthood (for immature lifestages)**
6. **Exposure to a suitable host**
7. **Finding a mate (unless a mated female adult enters)**
8. **Finding a suitable host for oviposition**

Refer to Preparedness Report section 3

Economic impact

Worldwide, the economic impact of this pest on horticultural industries has been significant. The magnitude of economic damage associated with spotted wing drosophila can in part be attributed to its ability to oviposit in, and feed on, ripening and fresh fruit. Financial loss can be incurred from:

- direct yield loss;
- reductions in saleable fruit;
- increased management costs (planning, trapping, infrastructure, chemicals and labour);
- disruption to current IPM plans for other pests;
- post-harvest sorting costs;
- quality downgrades;
- reduced marketability of fruit with no practical option for treating infested commodities or redirecting them to alternative markets; and
- potential market access control measures.

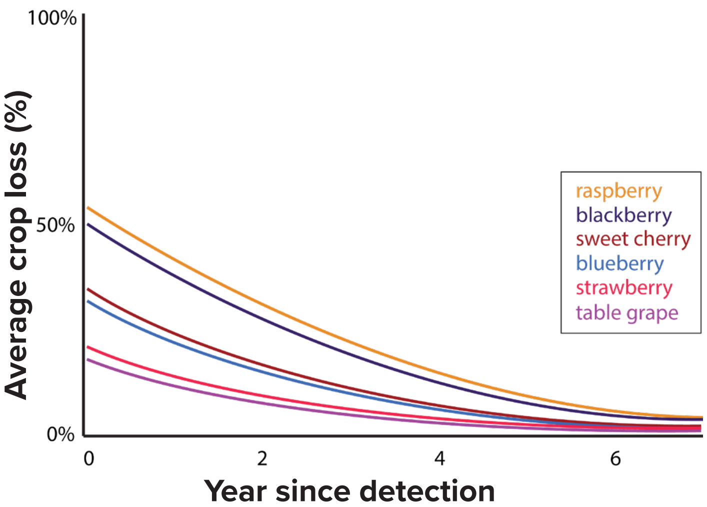
Based on international reports of crop losses variation in yield impact is associated with the crop type and time passed since spotted wing drosophila establishment in the region.

The association with crop type is likely to reflect intrinsic factors such as permeability of fruit skin or frost susceptibility, while the negative association with year since establishment likely reflects improvements in practices for managing the pest.

The economic impact potential of spotted wing drosophila to Australian horticulture has been investigated through development of a simulation framework by **cesar** that takes into account predicted spread, establishment and the locations of major host crop production regions.

The accumulated economic impact of spotted wing drosophila in Australia was predicted to be substantial at AUD195-257 million, with most of the impact arising from southern soft fruit growing regions. Simulating the incursion scenario using a variety of starting locations, such as Adelaide, Devonport, Cairns and Mildura resulted in little variation in accumulated economic impact six years post-incursion.

Refer to Preparedness Report section 3.4 for a detailed table of yield loss reported overseas.



Common name	Proportion reported yield loss			Number of reports
	Average	Min	Max	
Blueberry	14%	0	100%	56
Raspberry	**31%**	0	100%	52
Blackberry	24%	0	100%	45
Sweet cherry	17%	0	90%	17
Strawberry	8%	0	80%	45
Table grape	7%	0	35%	23

Above: Impact potential of spotted wing drosophila per crop based on international reports of yield loss due to infestation. The graph (left) is a schematic representation of reported yield loss over time since spotted wing drosophila detection, based on reports from the United States. The table (right) includes reported losses for those crops where the highest number of reports were available. The highest average yield impact is bolded. Source: Dr James Maino, **cesar**

Traps to monitor for spotted wing drosophila hang from a *Prunus* sp.

Research has shown that red is an attractive colour for this pest.

Refer to Preparedness Report section 4.1 for a summary of commonly used handmade and commercial traps for SWD.

Refer to Preparedness Report section 4

Planning surveys

Because spotted wing drosophila has not been reported as a severe insect pest of fruit in its native region, no effective monitoring tools were available prior to its invasion of North America and Europe in the late 2000s. To date there have been two major avenues that have led to early detection in incursion examples from around the world:

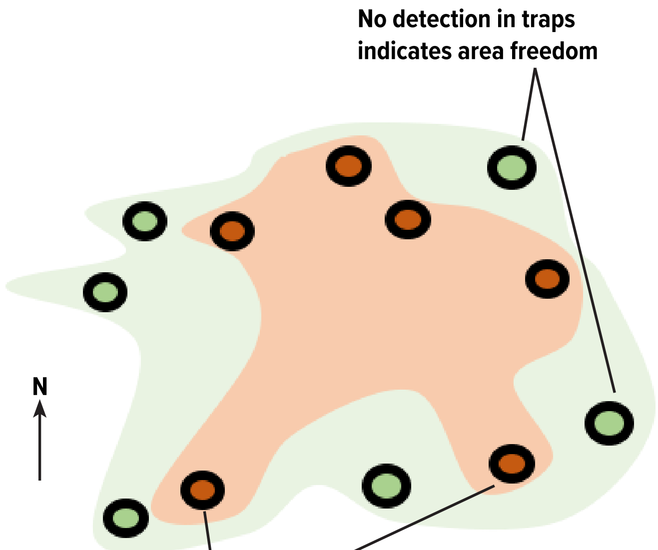
- targeted trapping; and
- reporting of crop damage.

A range of traps (malaise, bottle and tephri traps) baited with a variety of attractants (beer, wine, fruit, apple cider vinegar or a combination) have resulted in early detections. Since those early incursions improved attractants have continued to be developed.

In the event of a detection of spotted wing drosophila delimiting surveys will be required to determine the extent of the outbreak. These surveys will ensure that areas free of the pest retain market access and areas with the pest can put in place effective controls.

What is a 'delimiting survey'?

This is a survey conducted to establish the boundaries of an area considered to be infested by or free from a pest. The original detection location is used as a starting point to determine how the pest arrived and to where it may have spread (International Plant Protection Convention).



When planning surveillance in Australia, climatic suitability, land use, host availability, season, high risk points of entry, origin of fruit imports, and fruit transit and disposal must be taken into account.

Surveillance priorities for detection and delimiting spotted wing drosophila should consider:

- Trap catches do not reflect population density and experience overseas has shown that any level of trap capture may be indicative of a high population in the surrounding area.
- Larval extraction using sugar or salt flotation testing is a good indicator of the actual threat to crops.
- Crops, wilderness areas and urban environments are all possible detection sites (in Australia wild blackberry is a major weed could play a strong role in supporting populations).
- Landscape level factors, such as seasonal movement between hosts or between differing altitudes should be taken into consideration.
- The first trap captures in Europe generally occurred in July-October and increase over the season. The southern hemisphere equivalent to this first trap capture period is January-March. However, detection year-round may be possible in parts of Australia that have a similar climate to that of the United Kingdom (where SWD is trapped throughout the year).
- Common trap-and-lure systems designed for spotted wing drosophila show inconsistent performance.
- Often ripening fruits are more attractive than traps and lures.
- The surrounding landscape will play an important role in determining likely crop infestation dates, with recent overseas research drawing a link between proximity of woodland refuges and early infestation of fruit.

Surveillance should involve:

- visual inspection in high risk areas (e.g. edges of crops or orchards with mature fruit or vegetables);
- trapping with two forms of lure (e.g. a yeast-based lure and a wine/ apple cider vinegar-based lure); and
- fruit sampling via flotation testing using sugar water.

The type of sites where spotted wing drosophila is likely to first arrive are difficult to determine from overseas incursions, as the first site of detection is not necessarily the invasion epicenter. However, below are some considerations when planning early detection surveys:

- The most important pathway into Australia will likely be through fruit that is imported and then on-sold to consumers. Therefore, urban areas are likely to be where spotted wing drosophila populations will first occur.
- The invasion site and the 'spreading centre' of an invasive species are not always one and the same. The first invasion site is not always suitable for fast spread. This means that the spreading centre may stem from a secondary invasion site rather than the initial arrival point.
- Areas where fruit are collected, stored or particularly where waste fruit are dumped should be a focus of surveillance.
- The location of high throughput ports or airports are important to consider. This particularly includes ports that are high volume entry sites for fresh fruit imported from countries where spotted wing drosophila is present.
- Fruit distributors, wholesalers and retailers would be important to note as disposal of unsold imported fruit via wholesaler or retailer cull piles may present a risk.

The following is recommended for delimiting surveillance:

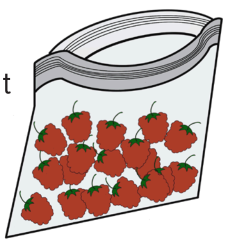
- Take into account tracing information to determine potential pathways for movement of material into and from the site of the initial detection.
- At each trapping site chose a crop that is a preferred host plant of spotted wing drosophila. It is also important to have traps in wild vegetation surrounding the crop.
- If suspicious damage is detected, fruit samples should be collected and traps should be placed around the affected area in an attempt to capture adults and diagnose the pest responsible for the damage.
- If spotted wing drosophila are confirmed, visual surveillance supported by trapping should be used to monitor the edges of the outbreak zone.
- Surveillance should be accompanied with awareness material, signs and personal visits to households and businesses within the surveillance zone and buffer zones.
- Detection year-round may be possible in parts of Australia. Outside of production season trapping should occur within non-crop hosts.
- Deploy traps in time to capture adult spotted wing drosophila straight after winter diapause.

Refer to Preparedness Report sections 4.2 and 4.3 for more information on detection and delimiting considerations.

Do you know how to conduct the sugar flotation test?

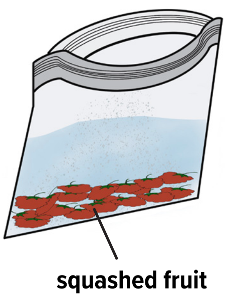
1.

Collect fruit and add 100g to a sealable bag.



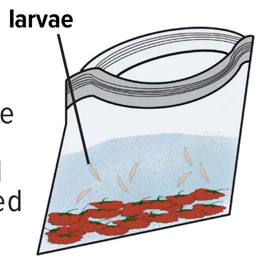
2.

Lightly crush fruit and add sugar solution (150g sugar:1L water).



3.

Leave for 30 minutes. Larvae will move out of the fruit and can be collected for diagnostic analysis.



Refer to Preparedness Report section 5

Options following detection

Eradication: Eradication potential will likely be low and will require very early detection during an invasion, and rapid host plant movement controls.

No country has eradicated spotted wing drosophila and it appears to spread very rapidly after initial detection. This is likely to be a result of several factors:

- The apparent rapid spread between regions and countries could be an artefact of the response post detection. Following an initial detection, increased awareness and surveillance occurs, which identifies and delimits populations that are already well established.
- The ability of spotted wing drosophila to spread long distances through human assisted movement is exacerbated by its cryptic nature (small eggs and larvae sheltered in fruit and superficial similarity to other *Drosophila* species). Therefore, it could go undetected for a long period of time.
- Spotted wing drosophila is highly fecund and has a wide host range, both in crops under commercial production as well as wild non-crop hosts.

While a range of synthetic lures are now available, they have been developed to assist management of the pest overseas, and their efficacy in supporting an eradication response is untested.

Management: Overseas spotted wing drosophila is managed using a highly integrated approach using chemical and non-chemical control tactics. Within Australia, the wide climatic zones spanned by berry, cherry, grape, and summerfruit growing regions will require management planning that takes into account local conditions.

Making production sites less favourable for spoted wing drosophila through cultural controls, and regular monitoring (visual crop inspections, trapping with lures, and fruit sampling) are of particular importance. In the case of an incursion chemical options would be quickly made available to Australian growers through the minor use and emergency permit system (and possibly through product registrations).

However, chemical applications do have limits on how useful they are for spotted wing drosophila control. Foliar sprays must be timed to target adult populations, thus monitoring is crucial. Eggs and larvae are difficult to control because they are protected inside the fruit. Many chemical products are non-specific and can impact on beneficial species, disrupting Integrated Pest Management programs and leading to pest flare. Limited chemical options and regular application of the same Mode of Action also increases resistance risk.

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Refer to Preparedness Report section 5

Awareness raising

Early detection of spotted wing drosophila will be important to ensuring that growers can execute effective management plans quickly. To achieve this, pro-actively raising the level of knowledge about this exotic pest within affected industries is of key importance. Raising industry preparedness at a regional level may use tactics outlined in the Improving Local Preparedness checklist below.

A key message that should be included in any communication is '*Protecting Australia from spotted wing drosophila will require an industry-wide approach. If you see anything unusual call the Exotic Plant Pest Hotline on 1800 084 881.*'
In the event of a spotted wing drosophila incursion clear messages about identification, impact and control will be important for facilitating an effective response or a transition to management.

Contents of Spotted Wing Drosophila Preparedness Basics may be used as a reliable reference when developing communications intended to raise awareness about spotted wing drosophila. If content is used in development of awareness material please include attributions as outlined in this document.

Resources

The Emergency Plant Pest Response Deed (EPPRD) and PLANTPLAN should be referred to, in conjunction with the spotted wing drosophila preparedness report. The EPPRD covers the management and funding of responses to Emergency Plant Pest incidents, including the potential for Owner Reimbursement Costs for growers. It also formalises the role of plant industry participation in decision making, as well as the contribution of affected industries towards the costs of executing national exotic pest responses.

Underpinning the EPPRD is PLANTPLAN, the agreed technical response plan for an Emergency Plant Pest incident. It provides nationally consistent guidelines for response procedures, outlining the phases of an incursion, as well as the key roles and responsibilities of industry and government during each of the phases.

Refer to planthealthaustralia.com.au for further details.

Improving local preparedness

- ✓ Ensure key staff members in your organisation are familiar with SWD Preparedness Basics.
- ✓ Circulate the **cesar** SWD PestBites identification video and SWD PestCase videos found at youtube.com/cesaraustralia.
- ✓ Circulate the Plant Health Australia SWD fact sheet.
- ✓ Encourage local host crop farms to source pre-emptive advice from your State Biosecurity Authority.
- ✓ Conduct local training in procedures for logging details of an infested site, containment of the site, taking a fruit sample and making a report.
- ✓ Identify potential local SWD pathway risks.
- ✓ Use Industry Biosecurity Plans to decide on actions to minimise local pathway risks.
- ✓ Support farm managers in biosecurity plan development.
- ✓ Add SWD as an agenda item for discussion at your next grower group meeting.
- ✓ Take Plant Health Australia's online biosecurity (BOLT) training.
- ✓ Set up a local working group that can be 'activated' to act as an information source and trusted communicator during an incursion.

Attributions

Content in SWD Preparedness Basics has been drawn from the SWD preparedness report, a product of project MT17005. The lead author of the SWD preparedness report is Dr Daniela Carnovale, Plant Health Australia, with input from the project team and the SWD Steering Group. SWD Preparedness Basics was developed by Dr Jessica Lye, **cesar**.

This guide should be referenced as:
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MT17005 research reports developed thorughout the project, as well as a variety of outreach materials, can be accessed by contacting Hort Innovation.

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