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

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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

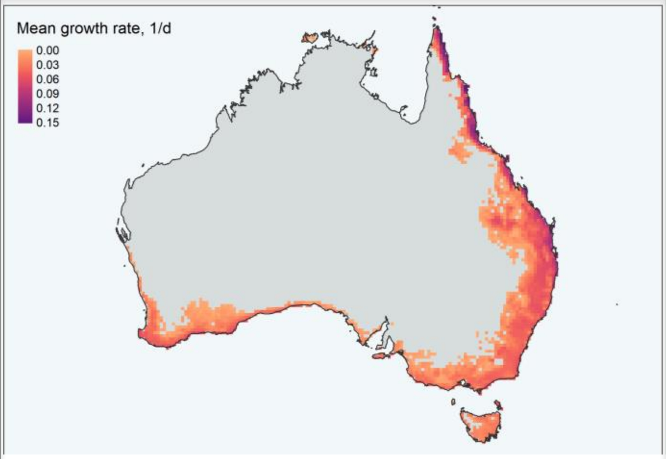
When the first detections around the world are viewed in aggregate, several commonalities can be seen that may help Australia consider pathways and possible sites of first arrival and detection. For a SWD incursion to occur via infested fresh fruit a number of steps must take place:

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/.](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.

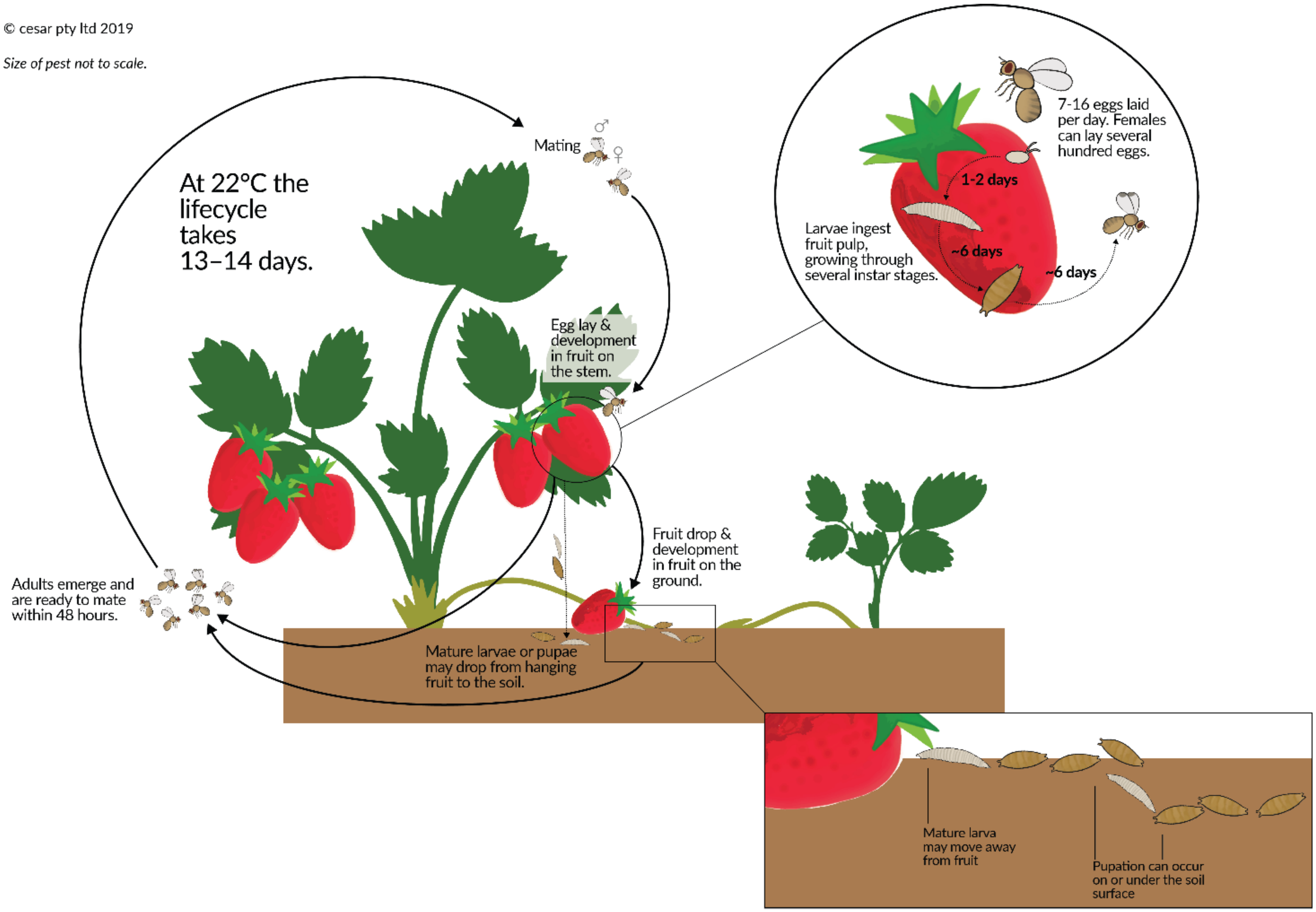


Figure 1: SWD lifecycle and development timeframes at 22 ℃

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

Figure 2: External damage to cherries(left), oviposition scars highlighted by red arrow and secondary rotting in cherry fruit (right)

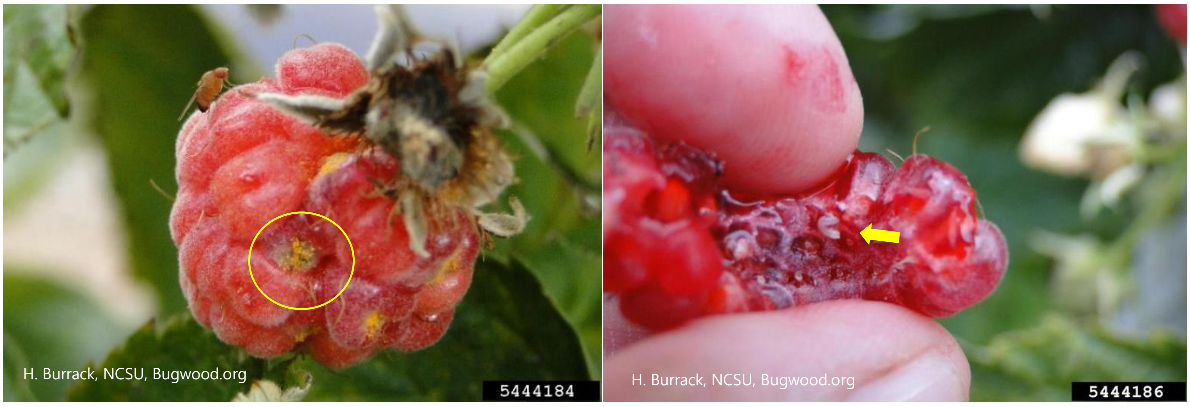


Figure 3: Damage to raspberries including impacted development of individual druplets highlighted in yellow circle (left), larva feeding on flesh indicted by yellow arrow(right)

Figure 4: Damage to strawberries with larvae present (left), eggs highlighted with yellow arrow, in strawberry flesh (right)

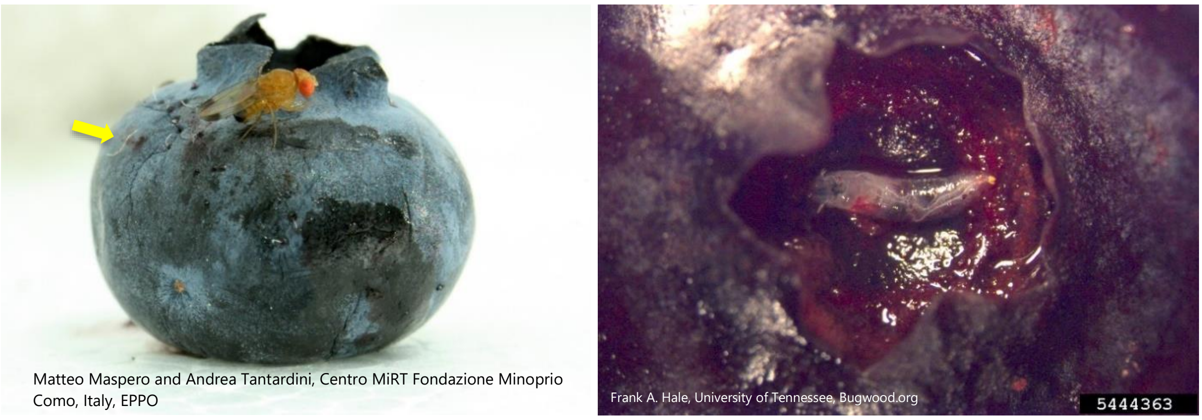


Figure 5: Damage to blueberries with oviposition sites Note the stipples caused by oviposition with filaments from the eggs protruding (left). larva feeding on a blueberry (right)

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/)

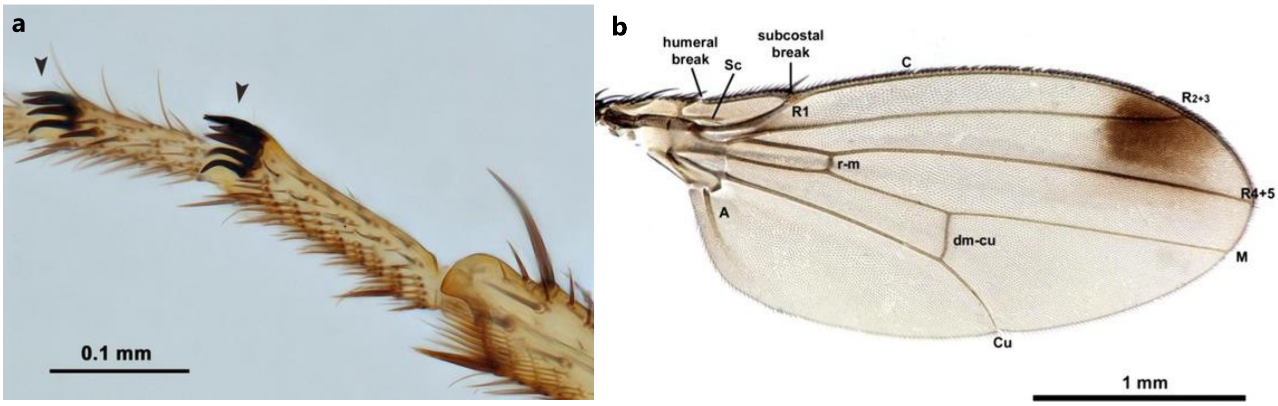


Figure 7: Drosophila suzukii- a) sex combs on first and second tarsomere of male's forelegs. b) right wing of a male with indicated veins and distinct spot (source EPPO 2013 PM 7/115 (1) Drosophila suzukii)

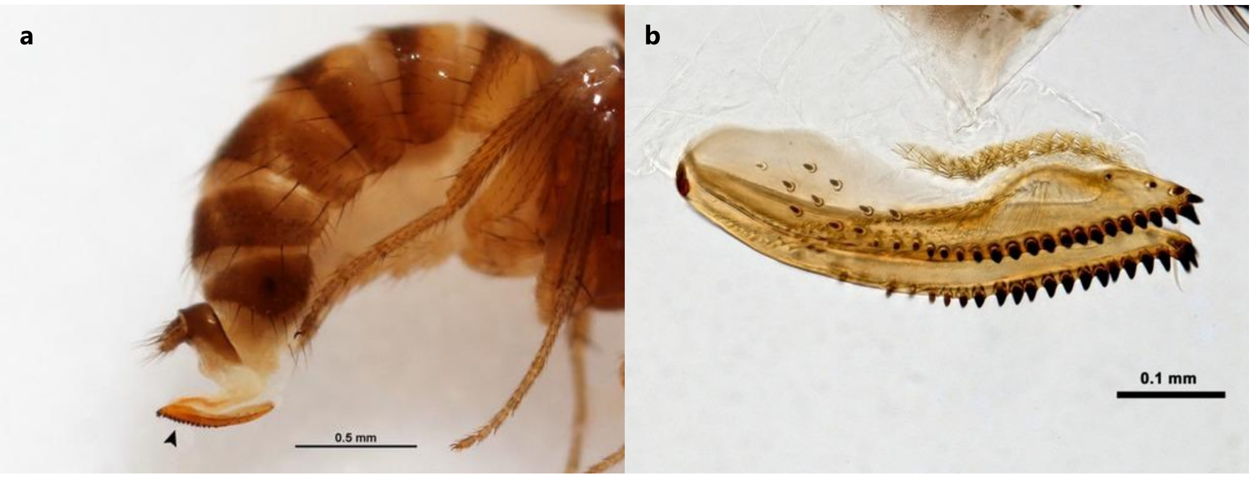


Figure 8: Drosophila suzukii - a) female with strongly sclerotized saw-like ovipositor. b) Drosophila suzukii - ovipositor with strong black teeth on valve margins (source EPPO 2013 PM 7/115 (1) Drosophila suzukii)

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.

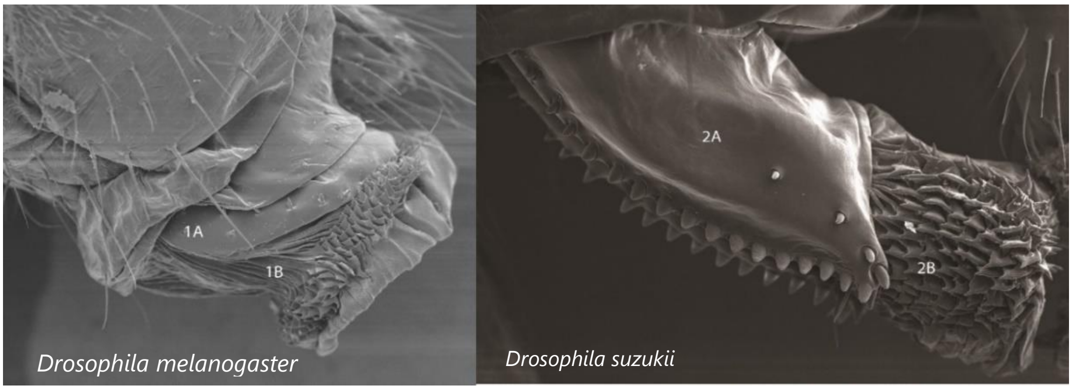


Figure 9: (Left) Drosophila melanogaster oviscape valve (1A) lacking sclerotized teeth and eversible membrane (1B) with small band of denticles. (Right) Drosophila suzukii oviscape valve (2A) showing extensive sclerotized teeth and eversible membrane (2b) with prominent denticles. Unpublished images 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.

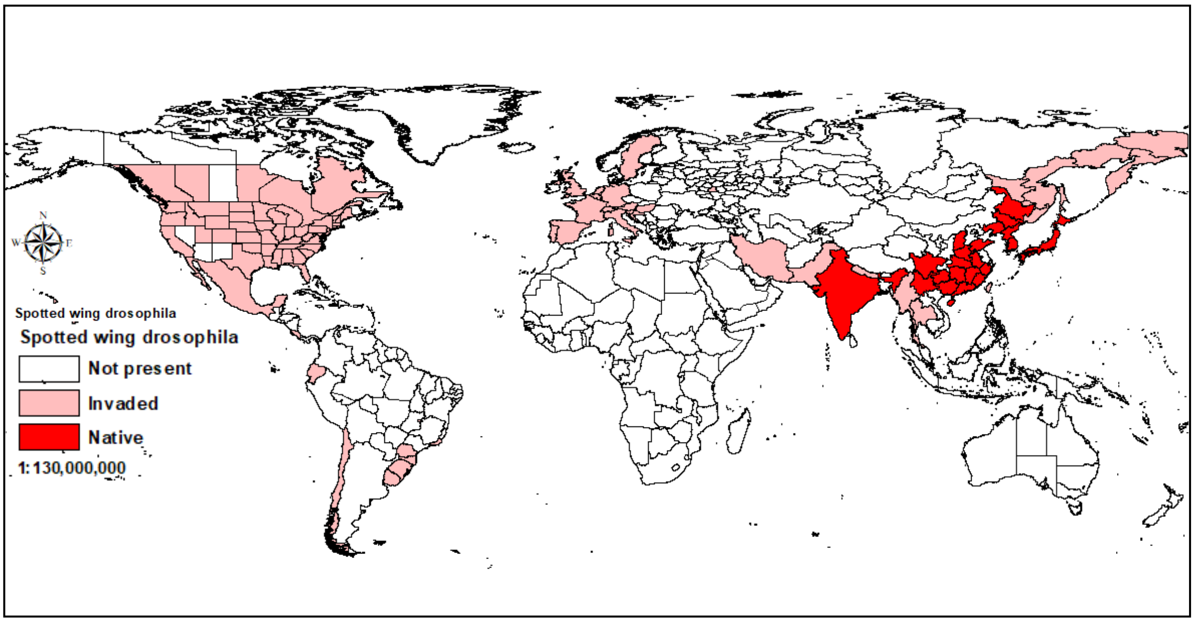


Figure 10. Global distribution of SWD as of 2018. Source: Ministry for Primary Industries (https://www.mpi.govt.nz/protection-and-response/finding-and-reporting-pests-and-diseases/priority-pests-plant-aquatic/horticultural-pests/spotted-wing-Drosophila/)

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).

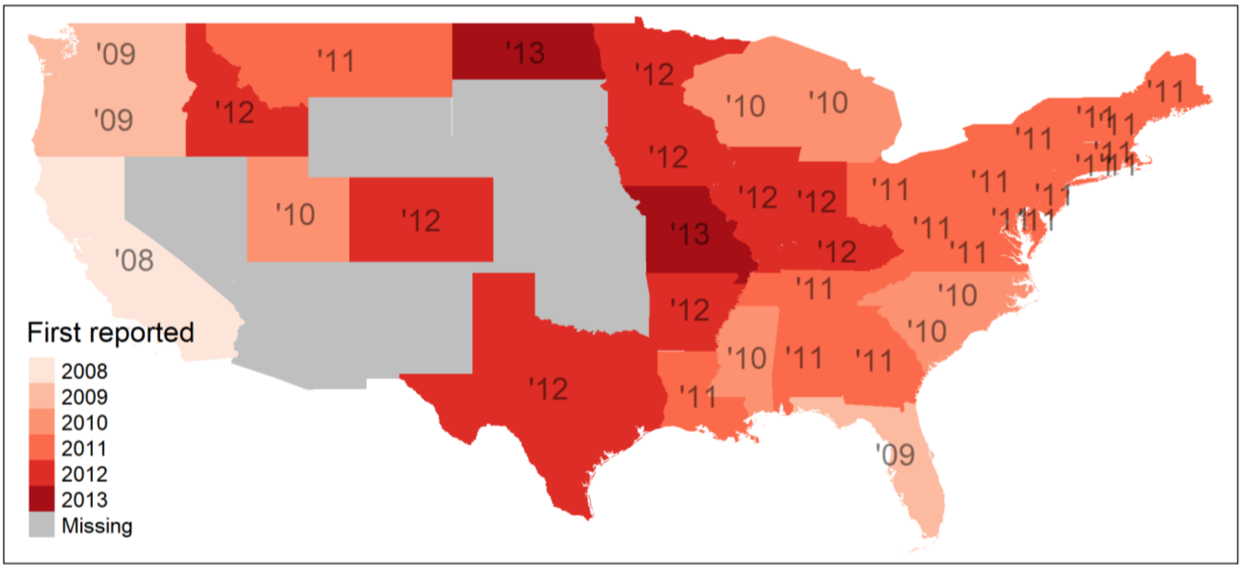


Figure 11: Reported spread across the United States mainland using state level data reported in Ørsted and Ørsted (2019). Numbers in states represent the abbreviated year of first report.

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)

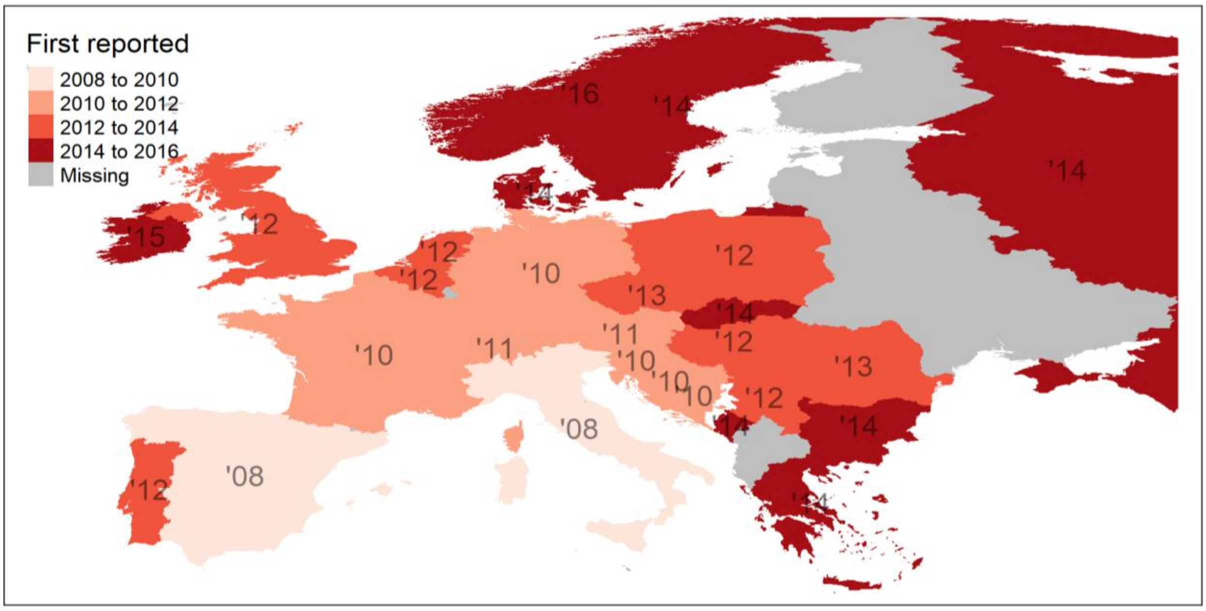


Figure 12: *Reported spread across the European mainland using state level data reported in* (Ørsted and Ørsted 2019) *Numbers in states represent the abbreviated year of first report*

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.

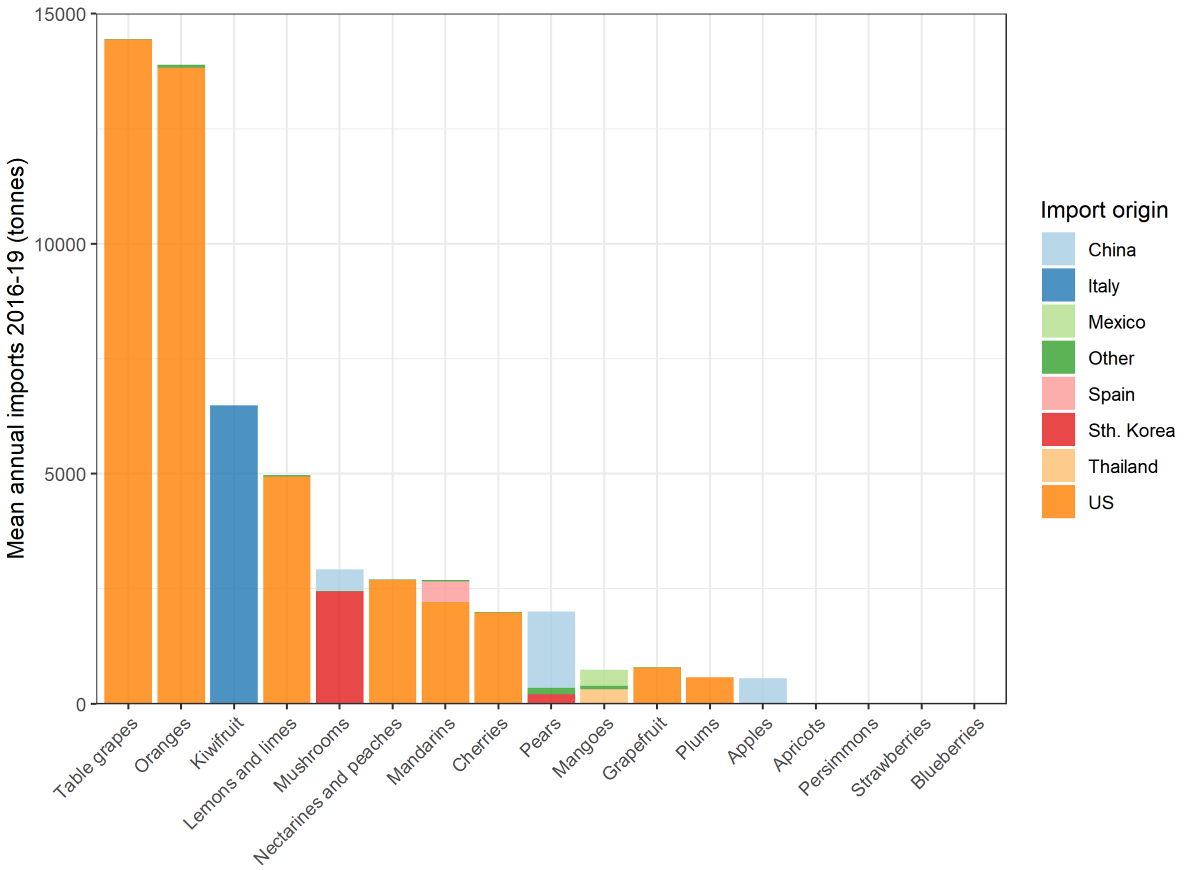


Figure 13: Annual Australian imports of fruits associated with SWD from countries in which SWD is known to occur averaged over years 2016-2019. Data sourced from the Australian Horticultural Statistics handbook (HIA 2019)

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.

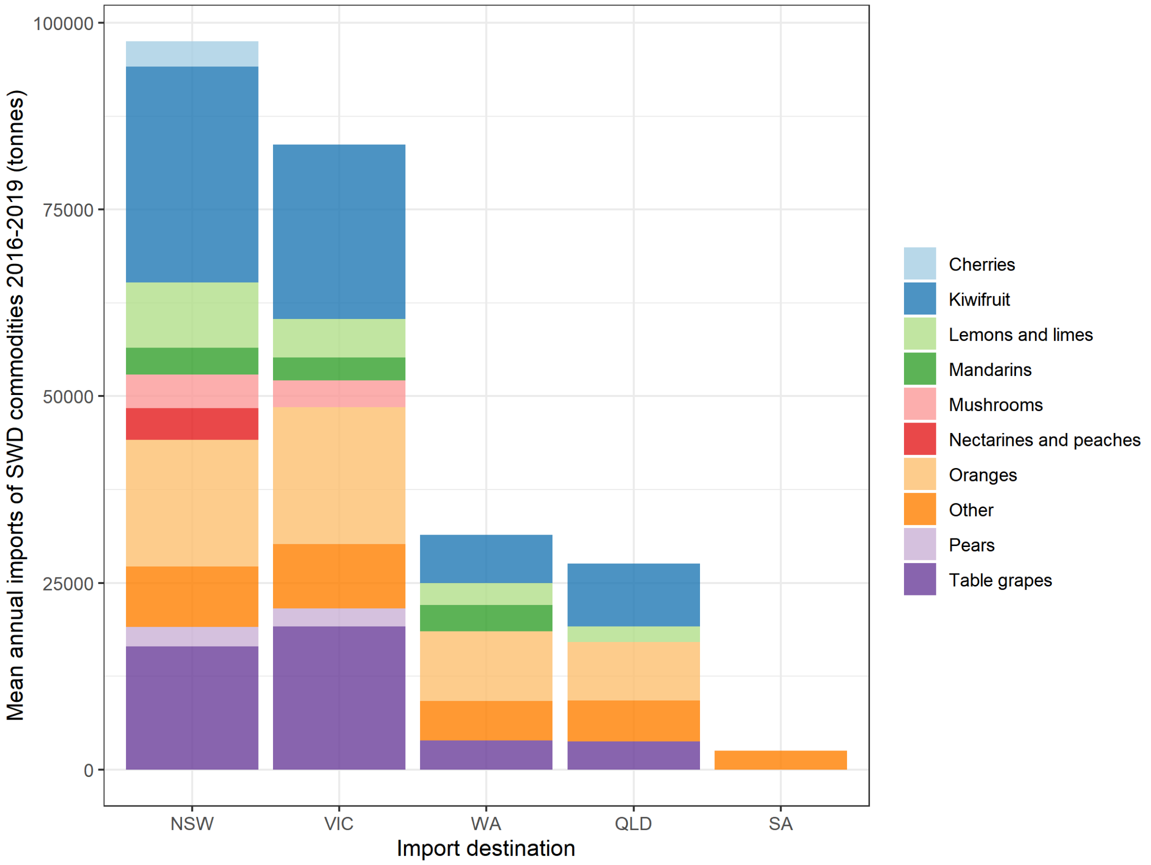


Figure 14. Quantity of SWD associated commodities (both primary and secondary) imported by Australian states averaged across over years 2016 – 2018 from countries both with and without SWD. Data sourced from the Australian Horticultural Statistics Handbook (HIA 2019). If imports for a state are less 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).

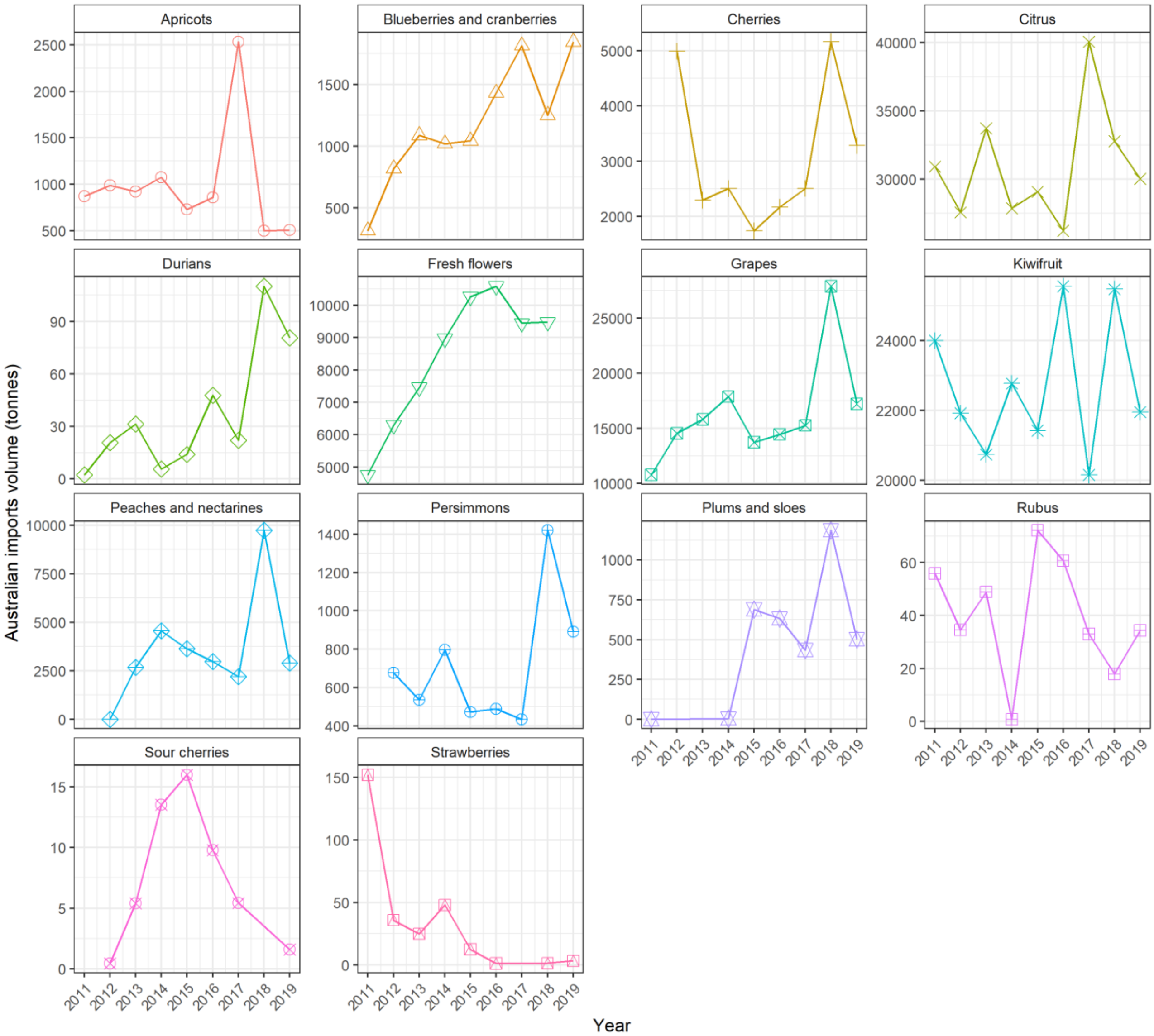


Figure 15. Volume of Australian imports of primary and secondary host commodities associated with spotted wing drosophila. Data is compiled from the UN Comtrade database (Comtrade 2015).

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.

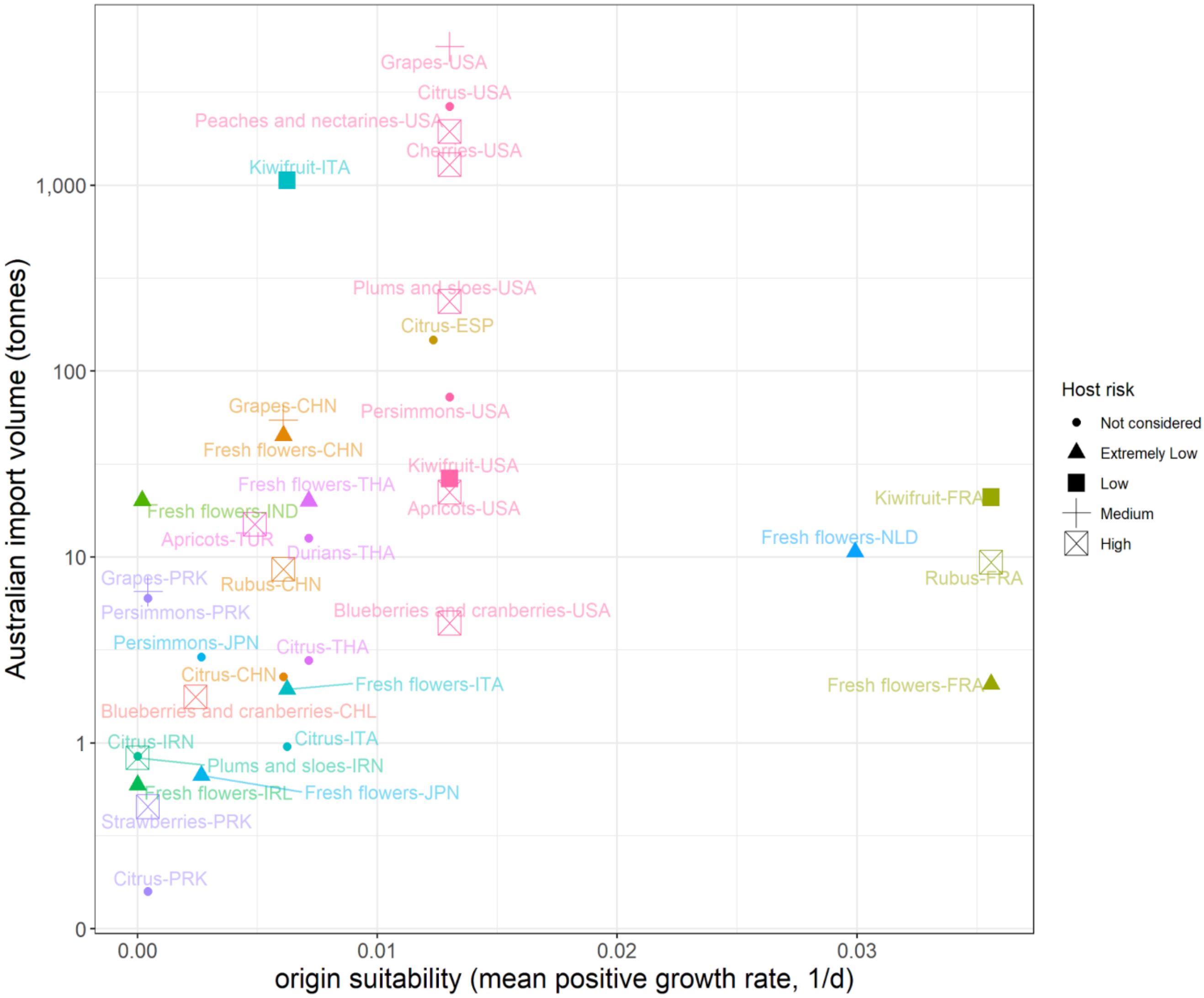


Figure 17: The total Australian import volume, environmental suitability at import-origin, and host-affiliation of SWD pathways. Trade volume data is compiled from UN Comtrade and averaged over 2008-2019. Host-risk is the host-specific importation risk as assigned in the Pest Risk Analysis (Department 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).

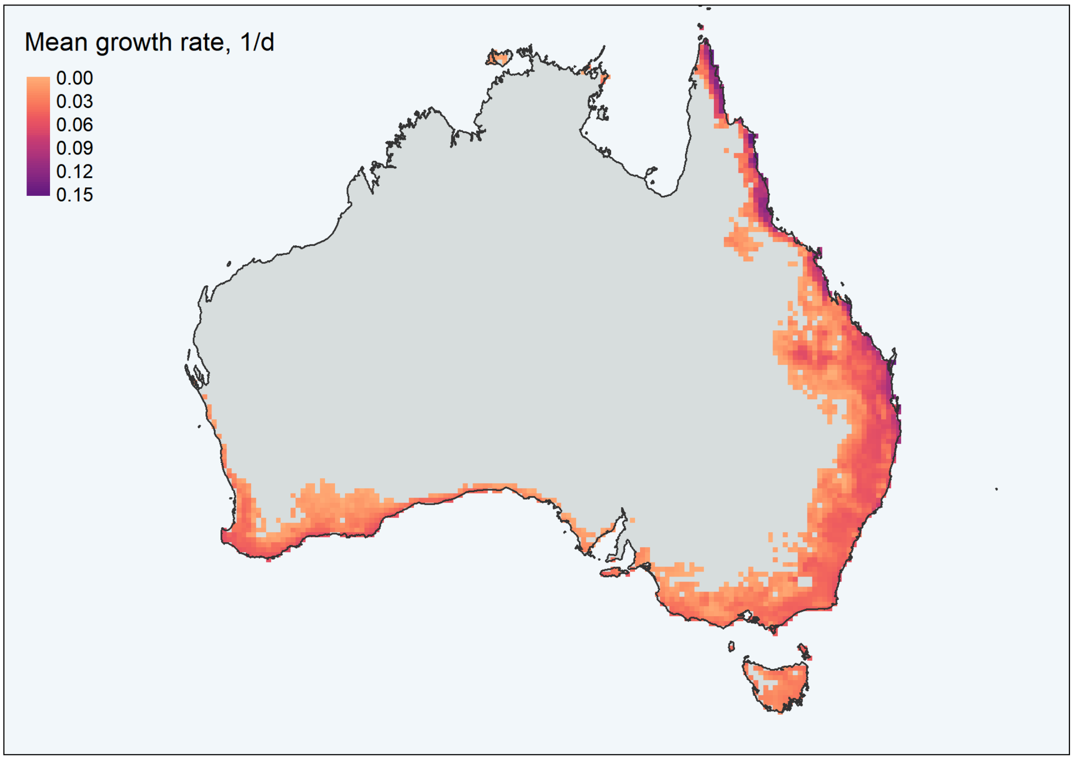


Figure 18: Modelled mean annual intrinsic population growth rate of SWD in Australia.

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).

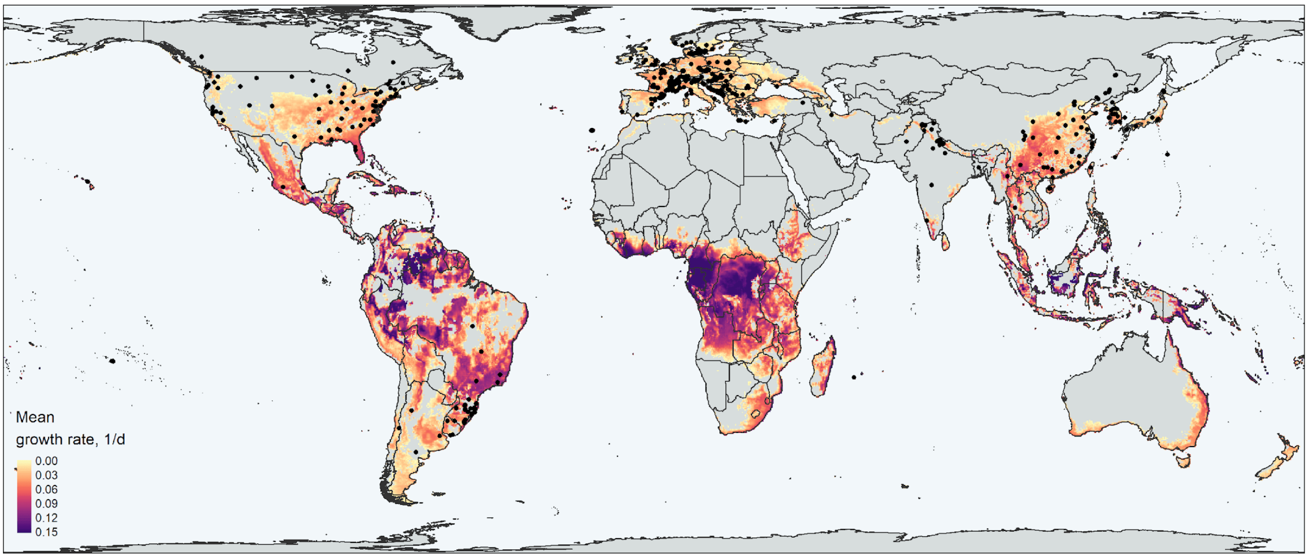


Figure 19 Modelled mean annual intrinsic population growth rate of SWD plotted against the current distribution (black circles) (Ørsted and Ørsted 2019).

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.

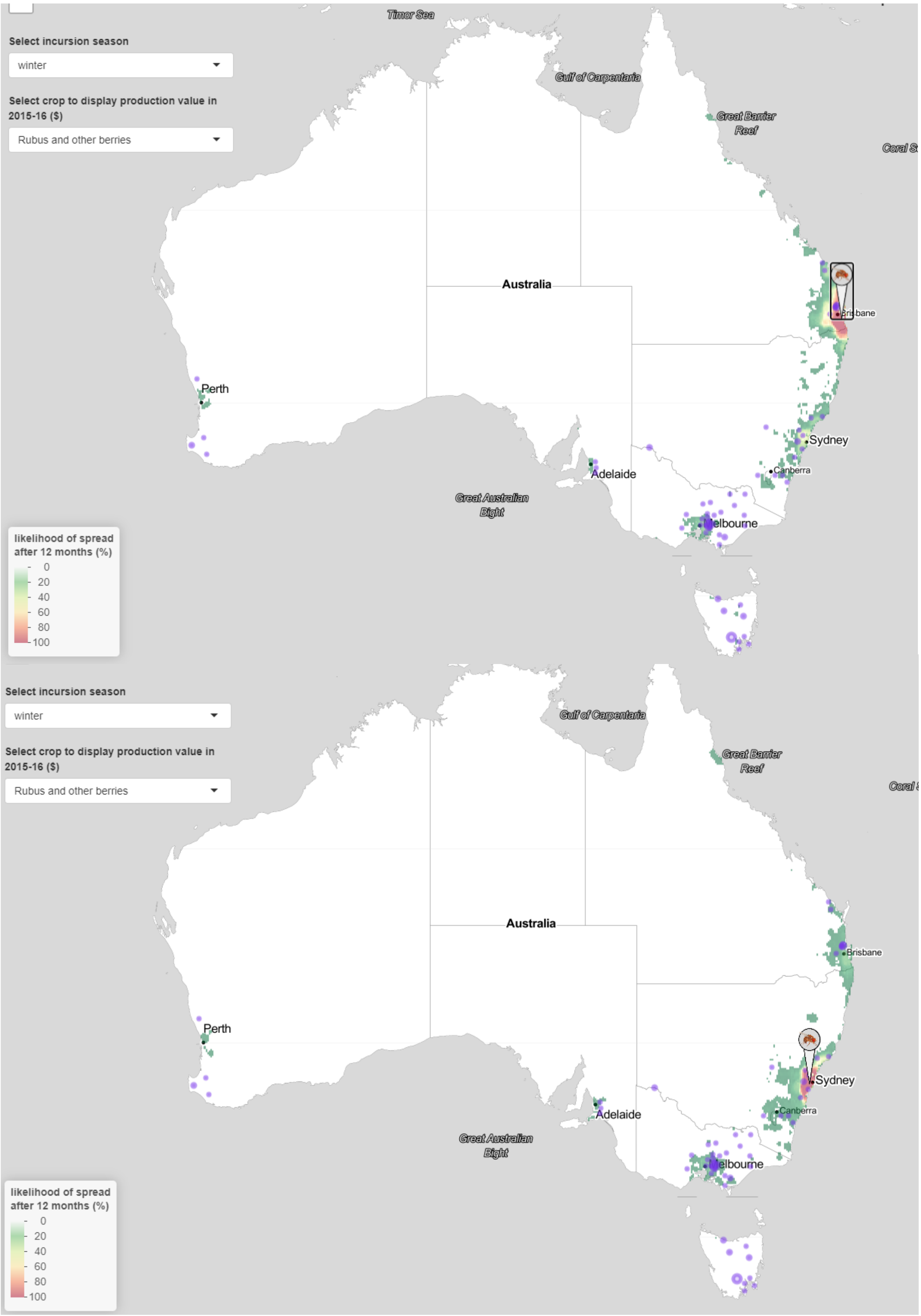


Figure 20: The strength of spread pathways where the color of each grid cell indicates the proportion of 100 replicated simulations in which SWD was present across 12 months following an incursion originating at the marker on Brisbane and Sydney. The spread represents unmitigated spread. Interactive 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.

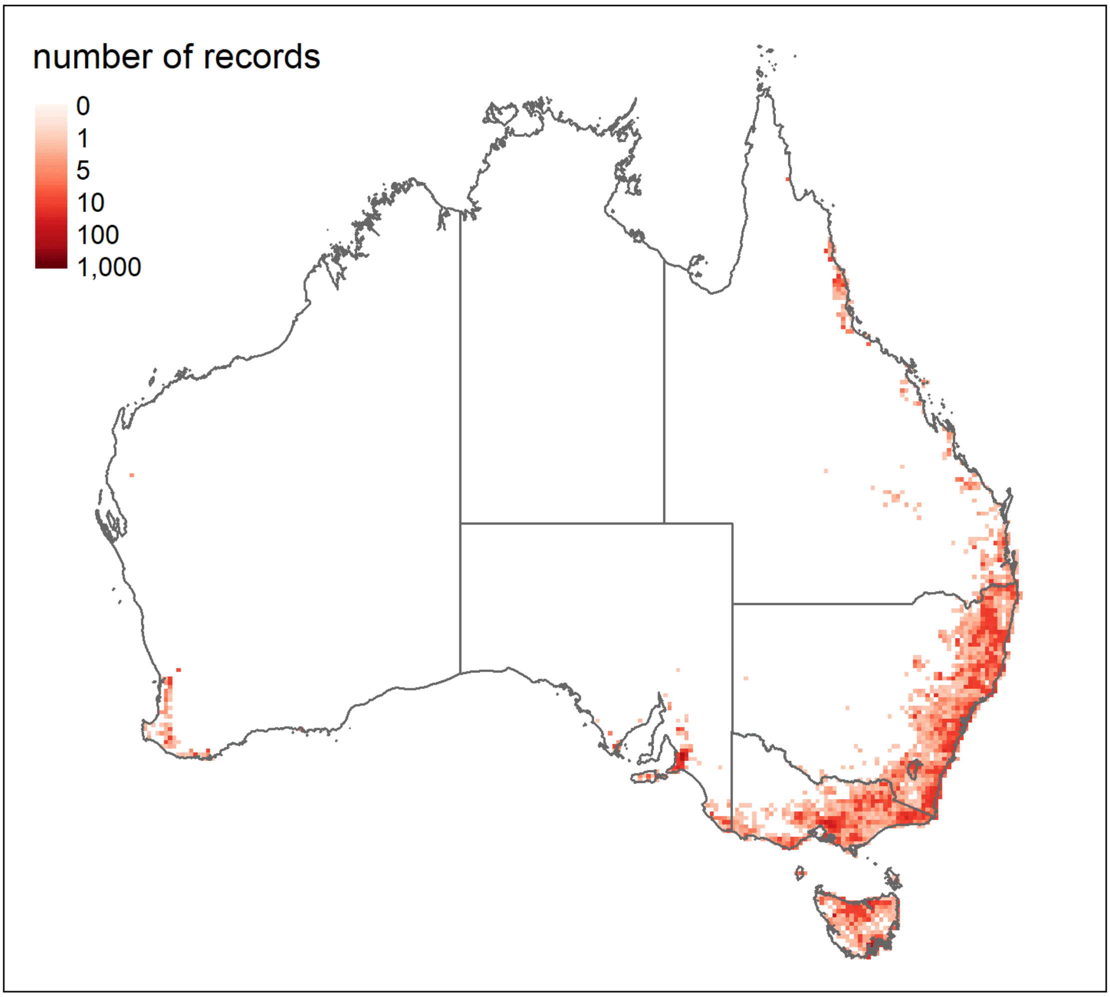


Figure 21: Spatial distribution of Rubus sp. reported in the Australian Living Atlas database suggest that the distribution of non-crop hosts is unlikely to be a limiting factor in the spread of SWD.

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

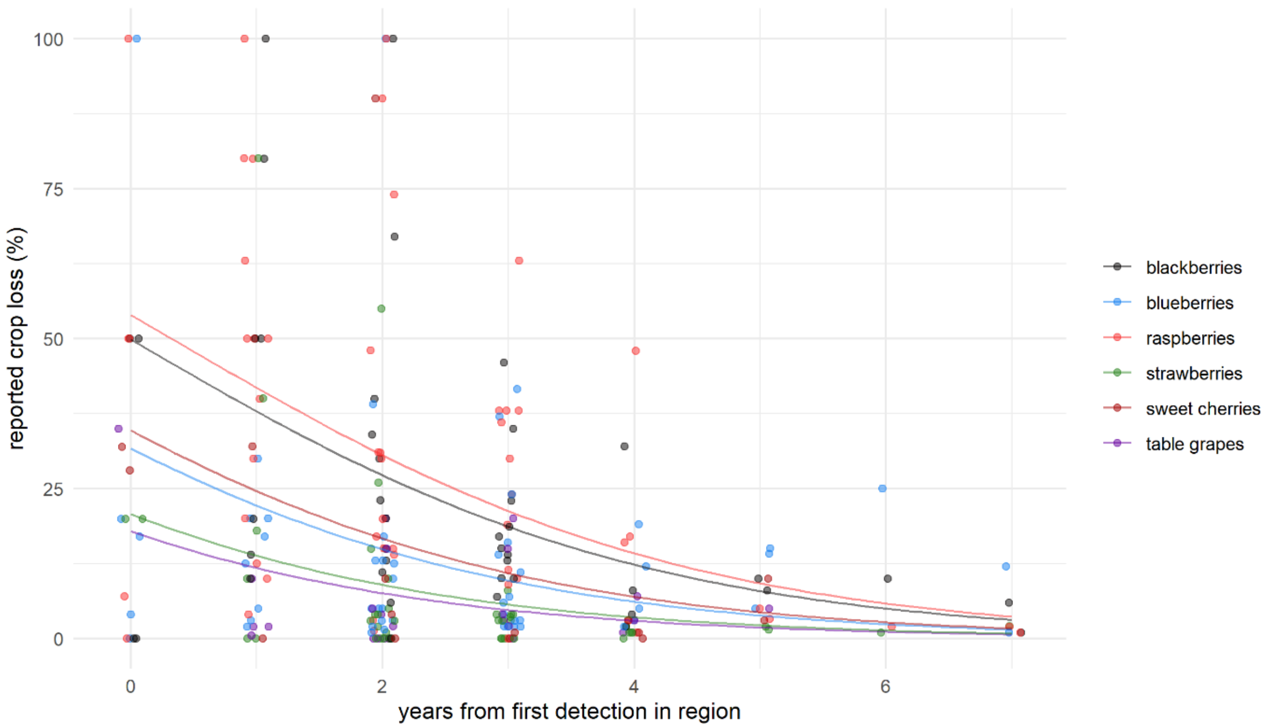


Figure 22: Negative relationship with reported crop loss and years from first detection in region demonstrating the effect of adapting management practices. Controlling for commodity effects (unique intercepts), the odds of any fruit being infested by SWD decrease by 39% for each year following initial 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).

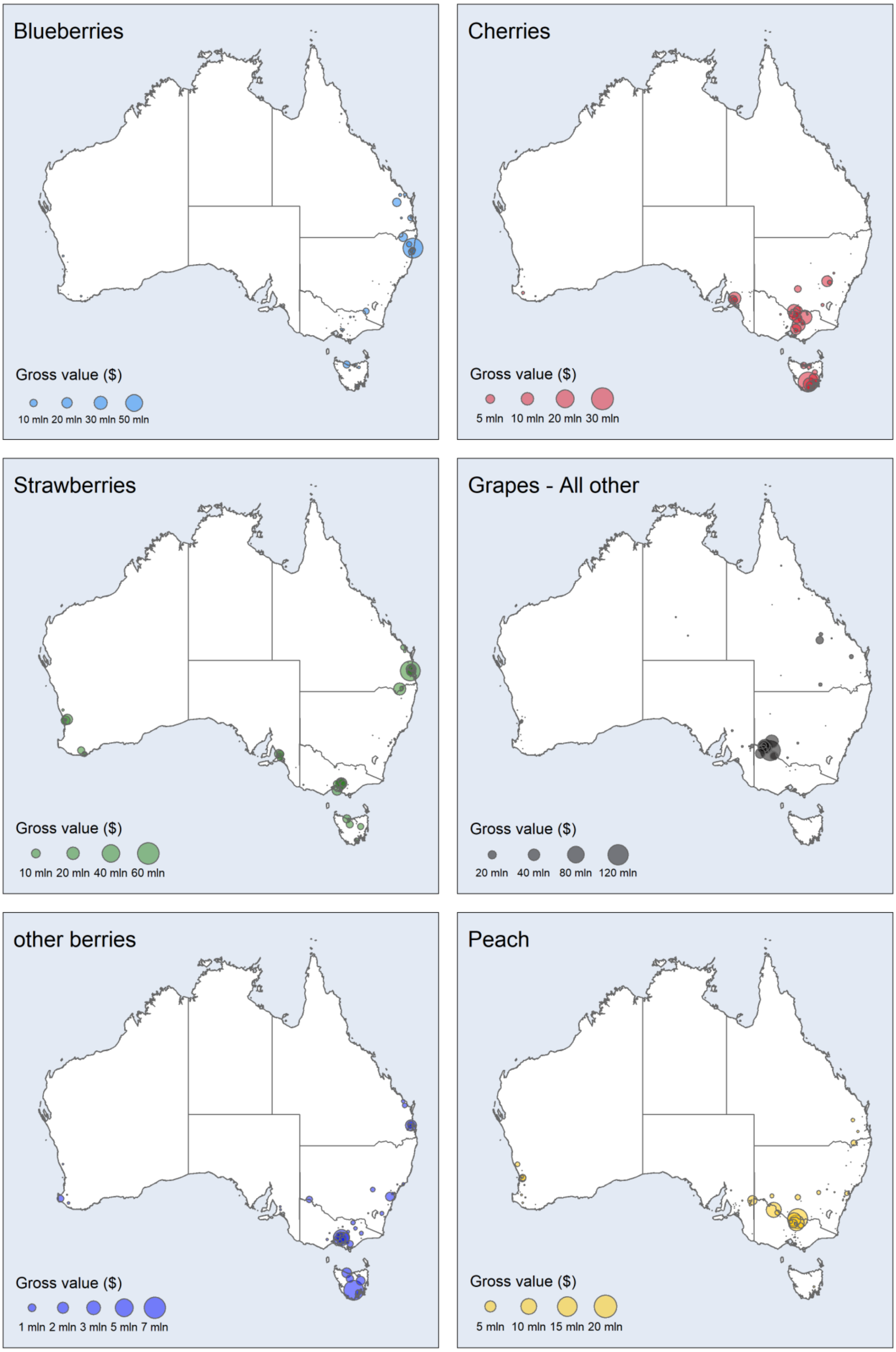


Figure 23: Distribution of the values of key affected commodity production in Australia based on ABS agricultural census data collected for 2015-16.

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).

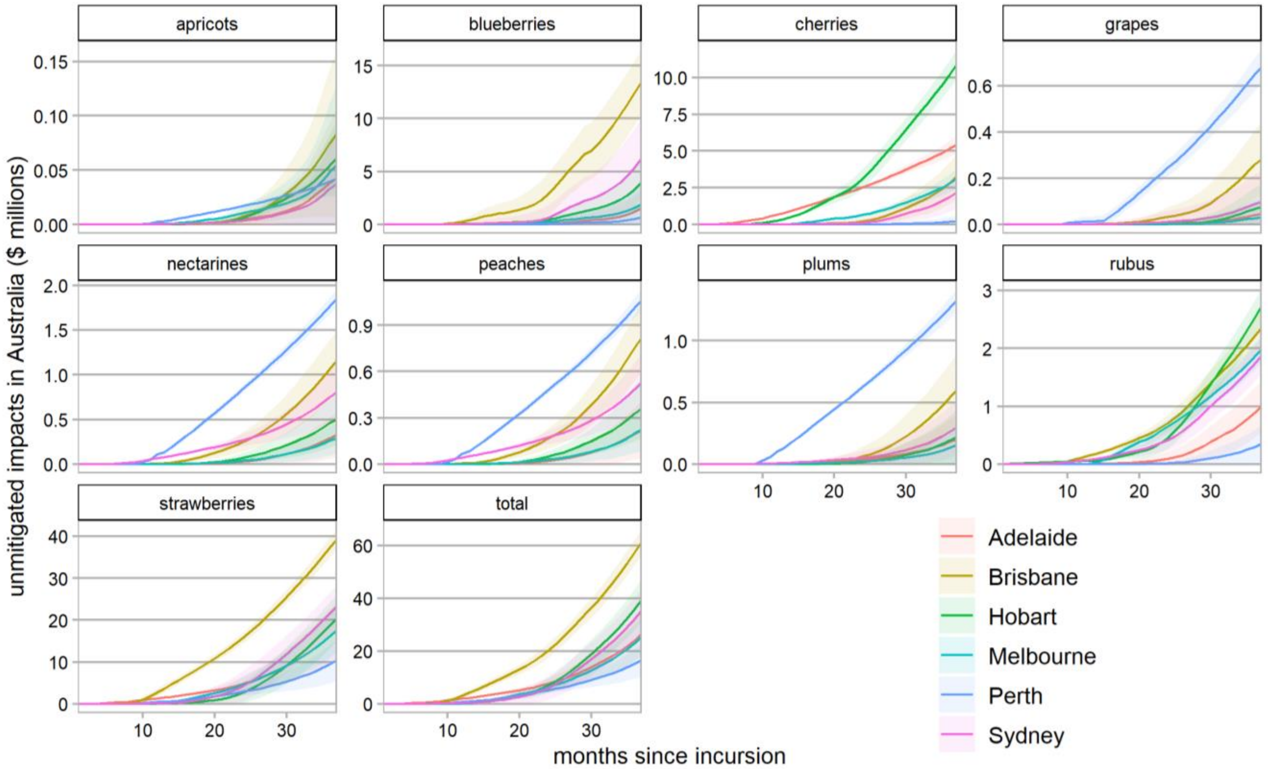


Figure 24: Accumulated national impacts through time dependent on incursion and commodity production location. A developed spread model for SWD (Maino 2020) which was able to account for: environmental conditions on SWD population growth, short-ranged dispersal, and human assisted dispersal was extended 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.

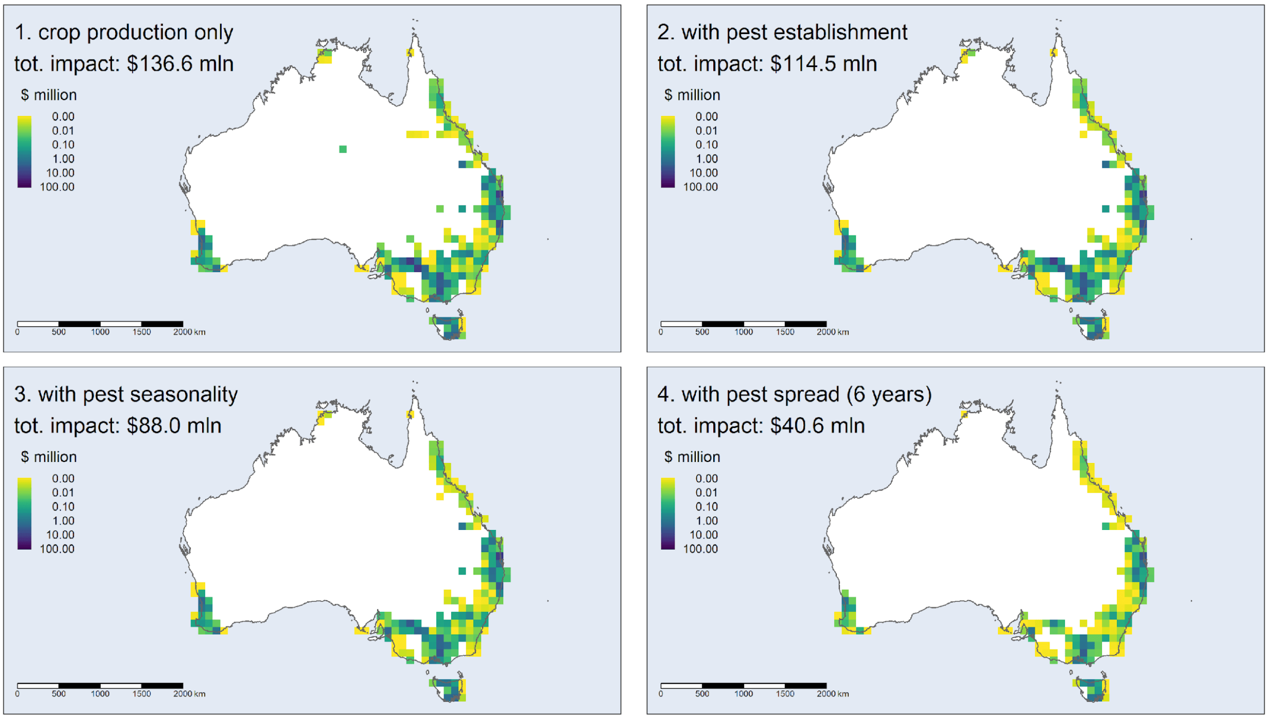


*Figure 25***.** *Annual pest impacts are can be estimated with incremental model complexity and differ based on whether impacts: 1) are assumed to be a simple proportion (10%) of gross production of susceptible commodities (top left), 2) are also restricted by climatic conditions that support population 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.

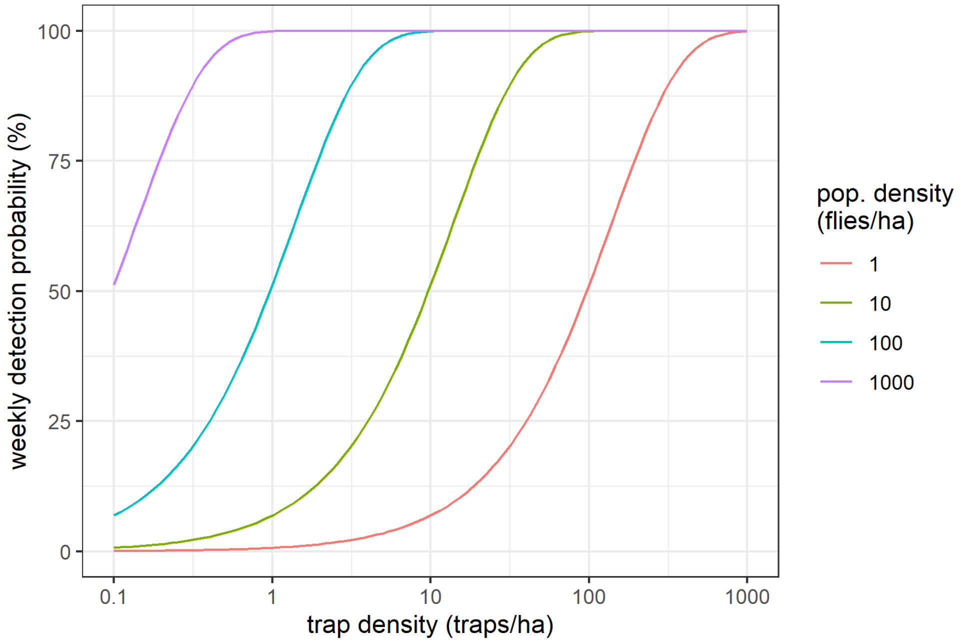


Figure 26: The estimated effect of surveillance effort on the probability of detection based on release and recapture study (Kirkpatrick et al. 2018b) for a single 20 × 30 cm double-sided, sticky, red panel trap (Great Lakes IPM, Vestaburg, MI) baited with a commercial SWD lure (Scentry Biologicals, 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)

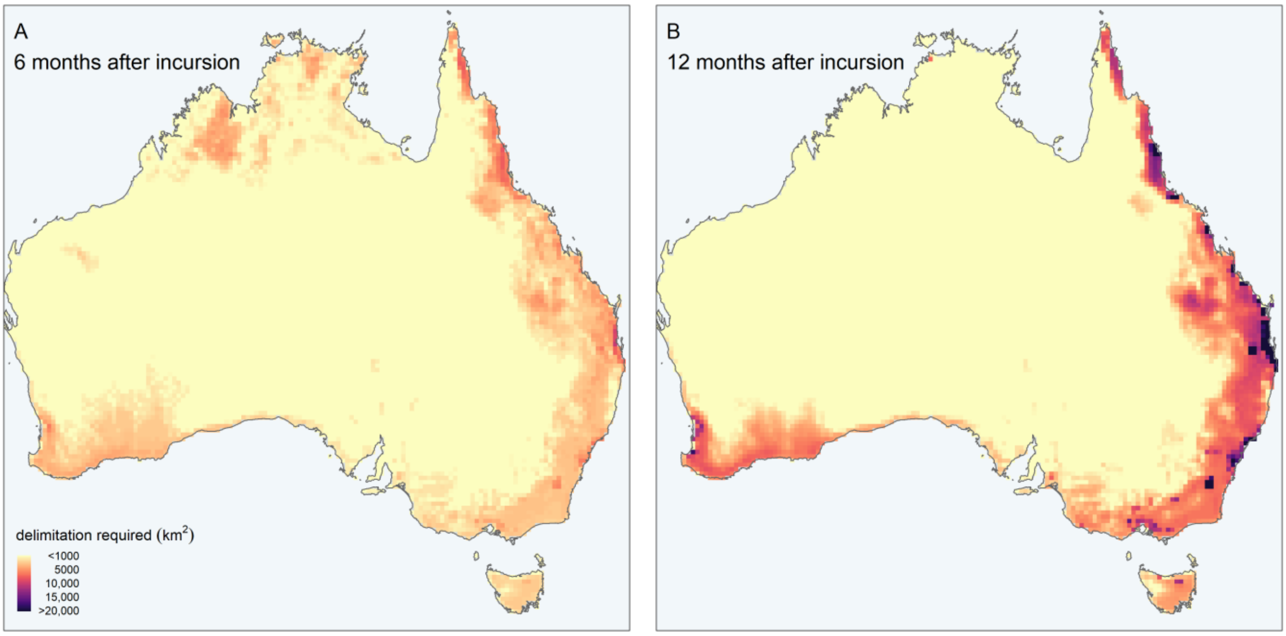


*Figure 27: For each grid cell an incursion is simulated with the grid cell as the origin. The resulting invasion extent after 6 months (**A**) and 12 month (**B**) is indicated by the grid cell colour. The area of trapping required to delimit spread depends on the duration since the initial incursion, 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