



## **Pest Risk Assessment:** *Drosophila suzukii*: spotted wing drosophila (Diptera: Drosophilidae) on fresh fruit from the USA

**FINAL**

MPI Technical Paper No: 2012/05

ISBN: 978-0-478-38861-9 (online)

ISSN: 2253-3923 (online)

June 2012

# Contributors to this risk analysis

## 1. Primary author

Jocelyn A. Berry

Senior Adviser  
Biosecurity Risk Analysis

Ministry of Primary  
Industries, Wellington,  
New Zealand

## 2. Internal Review

Deb Anthony  
Melanie Newfield  
Michael Ormsby

Biosecurity Risk Analysis  
Group

Ministry of Primary  
Industries, Wellington,  
New Zealand

## 3. External peer review

Dr John W. Armstrong

Quarantine Scientific Ltd., New Zealand

## Cover photo

Spotted wing drosophila, *Drosophila suzukii*, adult ♂

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Requests for further copies should be directed to:

Publications Logistics Officer  
Ministry for Primary Industries  
PO Box 2526  
WELLINGTON 6140

Email: [brand@mpi.govt.nz](mailto:brand@mpi.govt.nz)

Telephone: 0800 00 83 33

Facsimile: 04-894 0300

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## 1.1 SUMMARY

*Drosophila suzukii* (Matsumura), or spotted wing drosophila, is a temperate to subtropical species of vinegar or pomace fly native to Southeast Asia. It is an emerging invasive pest that is currently undergoing a rapid range expansion in North America and Europe. Although most other vinegar flies are attracted primarily to damaged, rotting or fermented fruit, *D. suzukii* is able to attack the fresh, ripe fruit of some hosts by laying eggs under the soft skin. The larvae hatch and grow in the fruit, destroying its commercial value. The host range of this fly is reportedly wide, including both cultivated and wild hosts. Cultivated hosts include many tree, bramble and vine fruits.

This assessment examines the risk posed by *D. suzukii* on approved commercial shipments of its known hosts from the USA: stone fruit (apricots, nectarines, peaches, plums, pluots), cherries, strawberries, table grapes. The risk posed by importing US blueberries is also assessed.

The likelihood of entry is commodity-dependent and is assessed specifically for each pathway. Evidence from the fly's native and introduced ranges suggests that this likelihood is low to moderate for apricots and high for all other commodities assessed.

The likelihoods of exposure and establishment are largely independent of the commodity association<sup>1</sup>. The likelihood of exposure is considered to be moderate for immature stages crossing the New Zealand border and high for adult stages.

The likelihood of establishment and spread is considered to be high throughout crop-producing areas of New Zealand, based on the fly's biology, phenology and current global distribution.

The economic consequences of establishment are likely to be moderate to high and the environmental and socio-cultural consequences are likely to be low. Effects on human health are unlikely.

## 1.2 PURPOSE

The purpose of this report is to assess the risks associated with *Drosophila suzukii* entering New Zealand via fresh produce imports from the United States of America.

The affected pathways include the existing trade in apricots, cherries, peaches, plums (and their interspecific hybrids, such as pluots and plumcots), nectarines, strawberries and table grapes.

## 1.3 BACKGROUND

*Drosophila suzukii* is an emerging pest which has recently spread to the USA. In response to the US detection, MPI imposed emergency mitigation measures requiring cold treatment or methyl bromide fumigation of host fruit of *Drosophila suzukii* exported from the USA to New Zealand in May and June 2010. These measures were based on initial risk analyses on stone fruit from the Pacific Northwest (USA) and table grapes from China. These current measures were intended to be temporary while MPI conducted a full risk assessment on all affected pathways and to provide the USA with an opportunity to propose equivalent measures.

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<sup>1</sup> though smaller and more delicate fruit species are likely to degrade more rapidly than larger, more robust species and may therefore limit the time available for larval development

## 1.4 SCOPE

The risk of *Drosophila suzukii* entering, establishing and causing unwanted impacts in New Zealand is examined in this assessment. The assessment is undertaken for imported, commercially produced fresh produce from the USA. In addition to the currently approved commodities, this assessment also includes blueberries, an important host in the USA. Blueberries are not currently imported fresh into New Zealand.

The scope of this assessment does not include import pathways involving nursery stock, seeds, cut flowers or foliage, illegal importation along the passenger pathway or any other risk pathway. It does not cover countries other than the United States; however it does include up-to-date information on the global distribution of this fly.

In this assessment of risk, it is assumed that current commercial production methods used in orchards in the USA do not include specific risk management activities in growing and preparing their produce for export.

## 1.5 HAZARD IDENTIFICATION

### Description

**Scientific name:** *Drosophila suzukii* (Matsumura, 1931) (Diptera: Drosophilidae)

**Other relevant scientific names:** *Leucophenga suzukii*

**Common name/s:** spotted wing drosophila, cherry vinegar fly

*Drosophila suzukii*, or spotted wing drosophila (SWD), is a small fly (2 to 3 mm in length) belonging to a group commonly known as vinegar or pomace flies. Although most vinegar flies are attracted to damaged, rotting or fermented fruit, *D. suzukii* is able to attack the ripe fruit of some hosts using its unique serrated ovipositor to lay eggs under the skin. The larvae hatch and grow in the fruit, destroying the fruit's commercial value.

### Taxonomy

The genus *Drosophila* as currently defined contains nearly 1500 described species, the majority of which are members of two subgenera: *Drosophila* and *Sophophora*. *D. suzukii* is classified in the subgenus *Sophophora*, species-group *melanogaster* and subgroup *suzukii* (Bock 1980, van der Linde & Houle 2008). However the genus *Drosophila* is widely considered to be paraphyletic and recent analysis has indicated that at least eight other genera are placed within this genus (van der Linde & Houle 2008). It is likely that the genus will be reorganised and that the species *suzukii* will be named *Sophophora suzukii*<sup>2</sup>.

### New Zealand status

*Drosophila suzukii* is not known to be present in New Zealand. Not recorded by Macfarlane *et al.* (2010), PPIN (2012; accessed May 2012).

### Status in the USA

*Drosophila suzukii* has been established in Hawaii since at least 1980 (Steck *et al.* 2009). The first record from the continental United States was in 2008 from **California**, on strawberries and caneberries (Bolda *et al.* 2010). Subsequent early detections were:

- **Washington and Oregon:** first detected in 2009, in strawberries and blueberries respectively (Walsh *et al.* 2011)

<sup>2</sup> Because of the scientific importance of the species *melanogaster* and the significant amount of published literature using this name a case was made to the International Commission of Zoological Nomenclature to preserve the name *Drosophila melanogaster* (Yeates *et al.* 2007).

- **Florida:** also identified in 2009, in traps (Walsh *et al.* 2011)
- **South Carolina, North Carolina and Louisiana:** first recorded in 2010 (EPPO 2010c)
- **Utah:** first recorded in 2010 (Davis *et al.* 2010), trapped again in 2011 (USU 2011, Stanley 2012)
- **Michigan:** first recorded in 2010, in traps (Good Fruit Grower 2010)
- **Wisconsin:** first reported in October 2010 (WDTAC 2010)
- **New Jersey:** reported by Langellotto (2010)
- **Connecticut and Rhode Island:** reported by Cowles (2011)
- **Maine:** detected in 2012<sup>3</sup>
- **Tennessee and Kentucky:** detected in 2012<sup>4</sup>

As of January 2012, SWD has been reported from 27 US states (Dreves *et al.* 2012). Additional reports are from the following states: Delaware, Georgia, Maryland, Maine, Montana, New Hampshire, New York, Ohio, Pennsylvania, Virginia, Vermont and West Virginia (pers. comm., Dr C. A. Stanley, Utah State University, 23 May 2012).

## General geographic distribution

**Summary:** *Drosophila suzukii* was first noticed infesting cherries in Japan by Kanzawa in 1916, but was not described by Matsumura until 1931 (Kanzawa 1935). The species is considered to be native to Southeast Asia (Bolda *et al.* 2010) and is widespread and abundant in Japan (Tamada 2009), China (Kai *et al.* 1993) and Korea (Lee 1964).

*D. suzukii* is reported from India (as the subspecies *indicus*; Singh & Bhatt 1988, Singh & Negi 1987); Pakistan (Amin ud Din *et al.* 2005); Myanmar, Taiwan and Nepal (Toda 1991), Thailand (Hauser *et al.* 2009, Toda 1991) and Far East Russia (Calabria *et al.* 2010).

*Drosophila suzukii* is recently invasive in the Americas and in Europe. In North America, it has been recorded from the USA (see previous section "Status in the USA") and Canada (British Columbia, ODA (2010a)). It has been reported from Central and South America including Mexico (NAPPO 2011) and Costa Rica and Equador (Calabria *et al.* 2010). It was first confirmed present in Europe from Italy in 2009 (EPPO 2010a) and more recently from Spain (Calabria *et al.* 2010), France (EPPO 2010b) and Germany<sup>5</sup>. Pratique (2010) estimated that it would take 5 to 10 years for *D. suzukii* to reach its maximum extent in the EPPO area (Europe and the Mediterranean), reaching 80% of the area of potential establishment after 5 years.

<sup>3</sup> [http://www.freshplaza.com/news\\_detail.asp?id=91353](http://www.freshplaza.com/news_detail.asp?id=91353)

<sup>4</sup> <http://mamgmusings.blogspot.co.nz/2012/02/spotted-wing-drosophila.html>

<sup>5</sup> [http://www.freshplaza.com/news\\_detail.asp?id=92870#SlideFrame\\_1](http://www.freshplaza.com/news_detail.asp?id=92870#SlideFrame_1)

**Table 1<sup>6</sup>: *Drosophila suzukii* – Global distribution in 2012**

Region	Country	Notes
Asia	China	Northern and southern China (Toda 1991); numerous locations from the north to the south and south west of China (Damus 2009); eastern China (Calabria <i>et al.</i> 2010, Cini <i>et al.</i> 2012). Recorded from the following provinces: Heilongjiang, Jilin, Liaoning, Beijing, Shanxi, Shandong, Jiangsu, Anhui, Shanghai, Zhejiang, Jiangxi, Hunan, Fujian, Guangdong, Hainan, Guangxi, Sichuan, Guangzhou, Yunnan (Kai <i>et al.</i> 1993).
	India	Kashmir (Hauser <i>et al.</i> 2009) and northern India (Toda 1991). Uttar Pradesh: Chamoli & Pauri region ( <i>Drosophila suzukii indicus</i> ; Singh and Negi 1989) and Gangolihat and Pithoragarg regions (Singh and Bhatt 1988). Punjab: Chandigarh and Manimajra (the type localities for <i>Drosophila suzukii indicus</i> ; Singh and Bhatt 1988)
	Japan	Widespread (Tamada 2009, Damus 2009); many Japanese localities including the Bonin and Ryuku Islands (Calabria <i>et al.</i> 2010)
	Myanmar	Two collection sites in and near Mandalay (Toda 1991)
	Pakistan	Islamabad (Amin ud Din <i>et al.</i> 2005)
	Russia	Russian Far East (Calabria <i>et al.</i> 2010)
	Korea	Numerous locations across South Korea (Lee 1966); North and South Korea (Calabria <i>et al.</i> 2010)
	Thailand	Present; no further information (Hauser <i>et al.</i> 2009, Toda 1991)
	Taiwan	Present (Toda 1991)
	Nepal	Present (Toda 1991)
Central America	Costa Rica	Common in collections from 1997 (Calabria <i>et al.</i> 2010)
	Mexico	First reported from Mexico in November 2011 in Michoacan (EPPO 2011, NAPPO 2011). Subsequently reported from Colima and Jalisco states (SENASICA 2012 communication to MPI).
South America	Ecuador	Rare in collections from 1998 (Calabria <i>et al.</i> 2010)
Oceania	Hawaii	Kaua'i, O'ahu, Moloka'i and Hawai'i (O'Grady 2002). O'Grady (2002) recorded it on Maui and Moloka'i "even at higher elevations in mostly pristine rainforest".
North America	Canada	British Columbia (Walsh <i>et al.</i> 2011)
	United States	As of January 2012, SWD has been reported from 27 US states (Dreves <i>et al.</i> 2012). See "Status in the USA"
Europe	France	Southern coastal France: Alpes-Maritimes, Corse, Var (EPPO 2010b); Montpellier (Calabria <i>et al.</i> 2010). South eastern France: Villeurbanne, Salaise-sur-Sanne (Seigle Vatte 2010) Corsica: (European Commission 2010a)
	Italy	First reported from the province of Trento (EPPO 2010a); from the Toscana region and also from natural forest environments in the province of Pisa; EPPO 2010d)
	Germany	Bavaria, Baden-Wuerttemberg and Rhineland-Palatinate <sup>7</sup>
	Slovenia	Western Slovenia, along the Italian border (European Commission 2010b)
	Spain	Rasquera, Barcelona (Calabria <i>et al.</i> 2010)
	Portugal	Biosecurity Australia (2010) cite a media report of <i>D. suzukii</i> attacking grapes in the Island of San Miguel, Azore Islands.
	Switzerland	Present (Cini <i>et al.</i> 2012)
	Croatia	Present (Cini <i>et al.</i> 2012)
	Austria	Present (Cini <i>et al.</i> 2012)
Belgium	Present (Cini <i>et al.</i> 2012)	

## Plant associations

*Drosophila suzukii* infests both cultivated and wild hosts. The host range is reportedly wide, including many tree, bramble and vine fruits (EPPO factsheet 2010, EPPO Alert List 2010).

<sup>6</sup> This table is based on Table 3.1 in Biosecurity Australia (2010)

<sup>7</sup> [http://www.freshplaza.com/news\\_detail.asp?id=92870#SlideFrame\\_1](http://www.freshplaza.com/news_detail.asp?id=92870#SlideFrame_1)



*D. suzukii* is unusual within the genus *Drosophila* in having the ability to attack whole, healthy ripening or ripe fruit. Although Sasaki and Sato (1995a) reported that *D. pulchrella* Tan, Hsu & Sheng also attacked healthy fruit in Japan, the vast majority of *Drosophila* species infest overripe and fallen fruit (Walsh *et al.* 2011). Kanzawa (1939, Japan) reported that *D. suzukii* oviposition on cherries took place preferentially on fully ripe fruit; damaged, spoiled and underripe fruit was less preferred.

The female's unusual serrated ovipositor apparently enables her to penetrate fruit to deposit her eggs (Steck *et al.* 2009). Several reports state that flies attack/infest "thin-skinned fruit" (*e.g.*, BCMAL 2009, Steck *et al.* 2009); however there is little information regarding what constitutes "thin-skinned"; whether this refers to the fruit skin being soft, or thin, or both. There are records indicating that it can oviposit in relatively firm-skinned fruit (Appendix 1), however it is not known whether these records result from oviposition in whole healthy fruit.

Kanzawa (1935) investigated the biology of the *D. suzukii* in Japan. He concluded that it was predisposed towards infesting living material, and "prefers to infest and develop in slightly under ripe perfect fruit". If the preferred host stages were unavailable, the fly was able to infest damaged or rotten fruit. Kanzawa (1939) published perhaps the most detailed host study. This work distinguished field-collected hosts from hosts that were infested in the laboratory, hosts in which the fly was able to oviposit into whole, undamaged fruit from hosts that had to be cut or damaged for oviposition to take place<sup>8</sup>; and hosts that produced many adults from hosts that produced few adults. According to Kanzawa (1939), the favoured hosts for *D. suzukii* in Japan are sweet cherries, flowering cherries, wild *Rubus* and grapes.

The generally reported host range (*e.g.*, EPPO 2010a) includes: *Actinidia* spp. (kiwifruit), *Diospyros kaki* (persimmons), *Ficus carica* (figs), *Fragaria ananassa* (strawberries), *Malus domestica* (apples), *Prunus avium* (sweet cherries), *P. domestica* (plums), *P. persica* (peaches), *Pyrus pyrifolia* (Asian pears), *Rubus idaeus* (raspberries), *R. laciniatus* (evergreen blackberries), *R. ursinus* (marionberries), and other blackberries (*Rubus* spp.), *Vaccinium* spp. (blueberries) and *Vitis vinifera* (table and wine grapes).

There is at least one published report of this species being reared from flowers (*Styrax japonicus*, Styracaceae in Japan; Mitsui *et al.* 2010). Biosecurity Australia (2010) also report *Camellia japonica* flowers as hosts (based on personal correspondence between M. Damus and M. Kimura in 2010).

Detailed host records and discussion are provided in Appendix 1.

## Commodity association

*D. suzukii* is associated with fresh ripe fruit and, rarely, flowers. Adults oviposit in fruit; larvae feed in fruit; pupation can take place both inside and outside of fruit (Kanzawa 1939, Dreves *et al.* 2009).

Four classes of commodities produced in the USA are identified:

**CLASS 1:** Commodities currently imported from the USA whose ripe, healthy, commercially-produced fruit is considered to be **likely or very likely** to host *Drosophila suzukii*.

This class includes: *Actinidia arguta*, kiwi berries; *Fragaria* spp., strawberries; *Prunus armeniaca*, apricots; *Prunus avium*, sweet cherries; *Prunus domestica* and hybrids, plums; *Prunus persica*, peaches and *Prunus persica* var. *nucipersica*, nectarines.

**CLASS 2:** Commodities currently imported from the USA for which there is significant uncertainty regarding the host status of *Drosophila suzukii* on ripe, healthy, commercially-produced fruit.

<sup>8</sup> It is very likely that some later publications have reported hosts from these categories indiscriminately.

This class includes: *Vitis* spp., grapes.

**CLASS 3:** Commodities not currently imported from the USA whose ripe, healthy, commercially-produced fruit is considered to be **very likely** to host *Drosophila suzukii*.

This class includes: *Rubus* spp. (caneberries) and *Vaccinium* spp. (blueberries).

**CLASS 4:** Commodities currently imported from the USA whose ripe, healthy, commercially-produced fruit is considered to be **very unlikely** to host *Drosophila suzukii*.

This class includes: *Actinidia chinensis* and *A. deliciosa*, green and gold kiwifruit; *Allium* spp., onions, shallots, garlic; *Asparagus officinalis*, asparagus; *Carica papaya*, papaya; *Citrus* spp., lemons, grapefruit, mandarins/ tangerines, oranges, tangelos, pomelos; *Malus x domestica*, apples; *Mangifera indica*, mangos; *Pisum sativum*, peas (green/ snow/ sugar snap); *Phoenix dactylifera*, fresh dates; *Punica granatum*, pomegranate and *Pyrus* spp., pears (except *Pyrus pyrifolia*, Nashi pears).

Supporting data is presented in Appendix 1.

## Potential for establishment and impact

*Drosophila suzukii* is a temperate to subtropical species native to Southeast Asia. It is a fruit crop pest and a serious economic threat to soft fruit such as cherries and other stonefruit, blueberries, raspberries, blackberries and others. This fly very recently became invasive in North America and Europe and could enter New Zealand through the importation of fresh produce. It appears to have the potential to establish in many crop-producing areas of New Zealand based on its current global distribution.

## Hazard identification conclusion

*Drosophila suzukii* or spotted wing drosophila:

- has the potential to be associated with commercial shipments of stone fruit (apricots, nectarines, peaches, plums, pluots), cherries, strawberries, table grapes and blueberries harvested in infested areas;
- is present in parts of the USA, is expanding its range rapidly and is not subject to any quarantine restrictions (ODA 2010b);
- is not recorded from New Zealand;
- has the potential to establish in New Zealand;
- has the potential to cause unwanted impacts.

*Drosophila suzukii* is therefore considered a hazard on commercial shipments of stone fruit (apricots, nectarines, peaches, plums, pluots), cherries, strawberries and table grapes (and potential commercial shipments of blueberries) imported into New Zealand from the USA.

## 1.6 RISK ASSESSMENT

### Biology

#### **Description and identification**

*D. suzukii* are small flies: pupae and adults are 2 to 3 mm in length, with yellow bodies and red eyes. Males have a distinctive black spot on the outer edge of the wing; females do not and require expert identification (ODA 2010a). The larvae of most *Drosophila* species remain undescribed (CPC 2010, factsheet for *D. melanogaster*), so it is difficult to conclusively identify immature specimens using morphological techniques; in general sequencing is required for accurate species-level identification. Eggs are clear to white, and are on average 0.62 x 0.18 mm wide (Kanzawa 1939), and are laid underneath the skin of the fruit (Bolda *et al.* 2010). Egg respiration takes place through two white tubes that protrude through the oviposition scar. These respiratory tubes are approximately 0.7 mm long (Kanzawa 1939, Table 3, referred to as “stalk”) and may be difficult to see with the naked eye, particularly on fruit with a hairy surface. Kanzawa (1939, Table 4) reported larval size as follows (length x width, reared on grape): 0.067 x 0.017 mm, 2.13 x 0.40 mm and 3.94 x 0.88 mm for first, second and third instars respectively. Pupae average 2.9 mm long x 0.99 mm wide for males and 3.18 mm long x 1.06 mm wide for females (Kanzawa 1939).

#### **Vector status of *Drosophila suzukii***

*Drosophila* species have been implicated as vectors of plant pathogenic fungi and bacteria. Feeding and oviposition wounds may provide access to secondary infection by both insects and pathogens, including fungi, yeasts, and bacteria causing additional losses over direct damage caused by larval feeding (Dreves *et al.* 2009, Hauser & Damus 2009, Walsh *et al.* 2011). For example Batta (2006) showed that *D. melanogaster* was capable of transmitting *Penicillium expansum* into sound, mature nectarine and pear fruit through feeding and oviposition punctures. This could result in production losses from unmarketable fruit and damage to wine production. However there do not appear to have been any reports of increased damage to crops caused by pathogens vectored by *D. suzukii*.

#### **Interceptions**

*Drosophila suzukii* has not been identified in interceptions at the New Zealand border (MAFBNZ 20/04/2012, Quancargo June 2012). However, interceptions of unidentified “*Drosophila*” and other drosophilids identified to species are relatively common. Live adults, larvae and eggs identified as “*Drosophila* sp.” have been intercepted at the New Zealand border on a wide range of fresh produce, including fresh produce from the USA, for example:

- Live adults: Consignment C2003/25790, “*Drosophila* sp.” detected on sea freighted peaches from the USA; Consignment C2004/253525, “*Drosophila* sp.” detected on sea freighted *Citrus* from the USA.
- Live eggs and larvae: Consignment C2005/141250, viable eggs identified as “*Drosophila* sp.” detected on air freighted nectarines from the USA; Lab number 29797, live larvae identified as *Drosophila* sp. detected on pineapples from the USA.

Since these interceptions pre-date the first US detection of the fly, it is highly unlikely that any of them represent detections of *D. suzukii*. However these data do indicate the ability of all drosophilid lifestages to survive transit on fresh produce from the USA and cross the New Zealand border.

In addition, interceptions of live drosophilids identified as “*Drosophila* sp.” have been made on known hosts of *D. suzukii* from countries where *D. suzukii* is present *e.g.* live larvae on cherries from Japan (M2000/6747; mail) and air freighted peaches from China (C2000/21169).

In summary, *Drosophila suzukii* has not been identified in interceptions at the New Zealand border, but interceptions of unidentified *Drosophila* species are common. All stages including adults have been detected alive at the border on a variety of fresh produce (including hosts of *D. suzukii*) air and sea-freighted from many countries including the USA.

*Within North America:* The California Department of Food and Agriculture (CDFA) have reported detections of *D. suzukii* in fruit moved within North America. Hoffman (no date) reported that larvae have been detected in cherries intercepted at CDFA’s border stations (and reportedly homegrown in Washington), and that “larvae intercepted as reportedly coming from Colorado, Washington, British Columbia and Alberta have also been found to be consistent with SWD DNA”. However it is noted that the actual origin of these intercepted cherries is unconfirmed. Biosecurity Australia (2010) cites an American detection of *Drosophila* larvae in commercial cherries exported from California to Florida which was suspected to be *Drosophila suzukii*.

*International:* *D. suzukii* has been not been intercepted by Plant Health Authorities on fruit being imported into Britain (Anderson *et al.* 2010) and there are no detections in the EPPO interceptions database.

### **Biology/phenology**

*D. suzuki* is a temperate to subtropical climate species (Mitsui *et al.* 2010). The life-cycle consists of the egg stage and three larval instars, followed by the pupal and adult stages (Biosecurity Australia 2010). Eggs are laid into fruit, or occasionally in flowers. Larvae can develop inside fruit or flowers. They may pupate within the host with their heads protruding from the fruit surface, or may leave the host and pupate in a substrate such as soil. Kanzawa (1939) considered that “pupation in the fruit seems to be the norm”. However Bolda (2009) reared many flies from strawberry and raspberry and found they always exited the fruit to pupate. Adult flies feed on dropped, spoiled and fermented fruit of breeding hosts (Walsh *et al.* 2011). In the absence of preferred hosts they have been found to feed on injured or culled apples and oranges, and even on oak tree sap (Walsh *et al.* 2011). Kanzawa (1939) reported the following developmental times at constant temperatures of 15°C and 25°C:

Life stage	Average time at 15°C	Average time at 25°C
egg	1 d 20 hr (44 hrs)	0 d 13 hr (13 hrs)
1st Instar	3 d 4 hr (76 hrs)	1 d 3 hr (27 hrs)
2nd Instar	2 d 19 hr (67 hrs)	0 d 23 hr (23 hrs)
3rd Instar	5 d 6 hr (126 hrs)	2 d 7 hr (55 hrs)
pupal period	10 d 13 hr (253 hrs)	4 d 13 hr (109 hrs)
total larval period	11 d 2 hr (266 hrs)	4 d 11 hr (107 hrs)
oviposition to adult emergence	22 d 17 hr (545 hrs)	9 d 15 hr (231 hrs)

Kanzawa (1939) used a maximum of 10 flies in calculating the above developmental times. Other studies report different results *e.g.*

- Sasaki and Sato (1995b) reported the number of days needed for development from egg to adult was approximately 30 (720 hrs, vs 545 hrs reported by Kanzawa 1939) at 15°C, approximately 19 (456 hrs) at 18°C, approximately 14 (336 hrs) at 22°C, and approximately 10 (240 hrs, vs 231 hrs reported by Kanzawa 1939 at 25°C) at 25°C and 28°C.
- According to Walsh *et al.* (2011), recent laboratory observations of the *D. suzukii* life cycle document development from egg to egg-laying female as 12–15 days (288–360 hrs) at 18.3°C
- Walsh *et al.* (2011) cited another study which found that at 21.1°C, development from egg to egg-laying female took a little more than a week (168 hrs).

In Florida (near Tampa) the number of days required to complete development from egg to adult in the field peaked at 38 days during the first week of February (mid-winter) and averaged about 10 days during late summer and autumn (mid-August to mid-October) (FDACS 2010).

Reports or predictions of the number of generations per year in various regions include:

- Kanzawa (1939) reported that flies reared under ambient conditions on grapes in central/northern Honshu, Japan completed up to 13 generations a year. This publication corrected earlier observations in Kanzawa (1935) of 15 generations a year
- Sasaki and Sato (1995b) reported 8 generations a year reared under ambient conditions in Fukushima Prefecture, central/northern Honshu with strawberry, cherry or apple for food. These authors stated that “the number of generations under natural conditions was not clear”
- Dreves *et al.* (2009) stated that “three to ten generations are predicted for most California production climates”
- Walsh (undated) reported that in California *D. suzukii* can produce as many as 10 to 13 generations per year; and predicted 5 or 6 generations in western Washington state, with first emergence likely between mid-June and early July
- 3 to 6 generations per year predicted in Oregon, depending on growing region and host availability (Langellotto 2010).

Kanzawa (1939) reported that oviposition takes place on warm days from April to November into (preferably) ripe cherry fruit in Japan. In laboratory trials 1 to 60 ( $11.5 \pm 4.5$  average) eggs were laid per day; 219 to 563 (382 average) were laid over the lifetime of the female (Kanzawa 1939). Kanzawa (1935, Japan) reported that 11 to 362 eggs were laid by a single female, with 38 eggs the greatest number laid in one day (stating “their fertility is prolific”). In the USA, Lee (2011a) reported that fecundity ranged from 61–85 eggs laid over 4 weeks, and was 419 eggs over the lifetime of flies given artificial diet. Kanzawa (1939) reported 62 adults emerged from a single cherry, however adults emerging from heavily infested fruit (40 to 62 adults) were very small and “appeared as if they were different species”. Mitsui *et al.* (2006) found that eggs were always laid singly on ripe cherries but that more than one egg could be laid when the cherries were less ripe.

*Developmental thresholds:* Kanzawa (1939, Japan) reported that adults become mobile above 5°C, that they were most active between 20° to 25°C and that their activity declined again at 30°C. Sasaki and Sato (1995b) calculated that the “developmental zero” (lower developmental threshold from egg to larva was 9.4°C, pupa was 8.4°C, and egg to adult was 8.8°C. Dean (2010) reported that the lower developmental threshold was at 8.9°C, that the temperature for optimal activity was 20°C and that the upper activity threshold was 31.7°C. Coop (2010) estimated a lower threshold of 10°C and an upper threshold of 30°C<sup>9</sup>. According to Walsh *et al.* (2011), degree-day models for *D. suzukii* are under development for the Pacific Coast states and Canada.

### **Overwintering**

Kanzawa (1939, Japan) reported that adults were the only life stage to overwinter, with some adults surviving from late September until the following July. The longest surviving female lived 301 days (average survival was 200 days). When temperatures fell in autumn, sexually mature females ceased oviposition and began again the following spring. Late-emerging females did not oviposit at all before winter, but began after overwintering (Kanzawa 1939). *D. suzukii* has been collected in Japan at localities with mean winter and summer temperatures of -5.1°C and 28°C, respectively (Kimura 2004) and it is firmly established on

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<sup>9</sup> According to Walsh *et al.* (2010), Coop’s model predicts initial spring activity to begin at 250DD, 50% egg laying on 490DD, and an accumulation of 744DD for development of egg to adult in the first generation, beginning January 1 and using a single sine curve calculation method.

the island of Hokkaido, where winters average  $-12^{\circ}\text{C}$  to  $-4^{\circ}\text{C}$  (Walsh *et al.* 2011). Kimura (2004) carried out thermal tolerance experiments (see below) and suggested that adults must overwinter in sheltered human habitation sites in the colder northern areas, or migrate from southern Japan every year. Sasaki and Sato (1995b, Honshu Island) found that overwintering survival under ambient temperatures in various substrates ranged from 0–23%.

In Oregon, although there was initial uncertainty about the ability of *D. suzukii* to overwinter (Dreves *et al.* 2009), survival was thought to be probable because winter temperatures in Oregon are milder than those in Japan. Preliminary trials by Walsh *et al.* (2011) showed that 6% of larvae and 13% of pupae survived to adulthood, and 39% of adults survived a 60-day exposure to fluctuating outdoor winter temperatures ( $0.72^{\circ}\text{C}$  to  $17.0^{\circ}\text{C}$ , mean =  $8.6^{\circ}\text{C}$ ), and that the surviving adult females were able to oviposit.

Coop *et al.* (2012) developed a model for overwintering mortality in the Pacific Northwest using laboratory developmental data and factoring in a “refuge factor” to account for field data. The refuge factor was added as a proxy to account for the behaviour of the adult fly in seeking shelter from the cold over a range from rural (open space with minimal protection) to human/urban influences (with maximal protection). This combined model predicted the most favourable areas for overwintering in the Pacific Northwest to be the coastal and southern regions with an overwintering survival of 25 to 100 out of 10,000.

### **Spring and summer**

In Yamanashi Prefecture in Honshu, the first adults appeared in traps in cherry orchards in early April, when spring temperatures increase above  $10^{\circ}\text{C}$  and overwintering adults become active (Kanzawa 1939). Infestation levels on cherries can build up rapidly due to the high reproductive potential of the fly. Sasaki and Sato (1995a) reported that in early June infestation levels on cherry in Fukushima, Honshu were 0–1.3%, but that these levels increased to 26–100% by the first week of July.

Kanzawa (1939) found that adults trapped in cherry orchards and vineyards during 1936 and 1937 were most numerous in June and July, followed by dramatic decreases in August, increases again in September and October, then gradual decreases into autumn. Kanzawa (1939) pointed out that the early adult population peak coincided with the cherry season and the late peak coincided with the grape season. In 1936 more adults were trapped in the later (grape) season, but in 1937 more adults were trapped in the earlier (cherry) season. It should be noted that the population peaks observed by Kanzawa relate only to numbers of adults trapped in cherry orchards and vineyards.

Research by Mitsui *et al.* (2010) on a range of *Drosophila* species and their hosts suggested that *D. suzukii* and other fruit- and flower-specialist species migrate seasonally between low<sup>10</sup> and high altitudes in central Japan. They reported the following observations for *D. suzukii*:

- at low altitudes, breeding took place on *Aucuba japonica* from mid April to late June, and on *Prunus* and *Morus* fruits from late May to late June. No breeding was observed in mid summer (July to late August) but breeding was detected again (“on some kinds of fruits”) in autumn
- at high altitudes it was detected breeding (“on some kinds of fruits”) in July and August.

Mitsui *et al.* (2010) suggested that adults move from low to high altitudes in early July, although they have the capacity to pass the summer at low altitudes and “some parts of its populations seem to stay at low altitudes”<sup>11</sup>. Because Mitsui *et al.* (2010) consider *D. suzukii* to be “rather heat tolerant”, they suggested that adults do not migrate to avoid summer heat

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<sup>10</sup> Low altitudes = suburbs of Tokyo, <1000m asl; high altitudes = Shiga Heights, 1600–2000m asl

<sup>11</sup> They state that Yamamoto (1992) and Beppu (2000, 2006) reported even in mid summer a few adult *D. suzukii* were collected at low altitudes in central Japan.

but, instead, to exploit resources at higher altitudes or to escape from resource-poor conditions at lower altitudes. Breeding of other flower- and fruit-feeding drosophilids also was rarely observed in summer at low altitudes.

*Drosophila suzukii* has established and spread through much of Florida (FDACS 2010). Dean (2010) plotted 2009 (the first year of the incursion) adult numbers against average temperature and showed that catches were highest in the relatively cool winter months.

Preliminary results from Climex/Maxent modelling studies indicated that *D. suzukii* has the potential to establish along the west coast of USA and Canada (e.g. British Columbia), and in large eastern parts of USA (Damus 2009).

### **Humidity**

Some authors consider that the distribution of *D. suzukii* may be limited by low humidity, e.g.:

- Walsh (undated) considered this species to have a “preference for high humidity” (no data given), and predicted that this would make the warmer and drier areas of Washington state less likely to incur damage than other areas
- Damus (2009) reported that *D. suzukii* is limited in Asia “by cold in the winter, by humidity during the growing season, and apparently by heat in the south”, and Hauser *et al.* (2009) speculated that the lack of damage to crops reported from Europe could be due to the dry Mediterranean climate, which they stated to be “not the preferred condition for *D. suzukii* according to ecological simulations run by Martin Damus”
- Van Steenwyk (2010) stated (no data given) that *D. suzukii* “prefer high humidity and moderate temperatures in the mid 70° F” (around 24°C)
- EPPO (2010f) stated (no reference given) “the species cannot tolerate high temperatures if humidities are low and, in the southern Mediterranean areas, the species may survive only in irrigated crops”
- Calabria *et al.* (2010) noted that in Europe, as in western North America, *D. suzukii* is expanding its range northwards. They considered that this pattern fits ecological simulations by Hauser *et al.* (2009) indicating that a dry Mediterranean climate is not a preferred condition.

There have been some subsequent suggestions that the combined effect of low humidity and high temperature is likely to be unfavourable to the survival and reproduction of *D. suzukii* (Biosecurity Australia 2010) and may be a limiting factor in grape-growing areas such as California’s Central Valley (Van Steenwyk 2010).

Some distributional and phenological data from the native and introduced ranges of the fly appear to support these suggestions. Beers *et al.* (2010) considered *D. suzukii* to prefer a moderate climate, such as that found in the coastal areas of the US west. Although populations have become established in California’s Central Valley, they observed that activity was suppressed by high summer temperatures (43°C to 46°C) and resumed when temperatures dropped off in autumn. Similarly, in Florida, peak *D. suzukii* finds (trap catches) occurred during winter, while finds in the summer-autumn period (to date) were very low (Dean 2010).

Nevertheless it is not known with any degree of certainty if, and by how much, population levels are likely to be reduced by hot dry conditions. For example:

- *Drosophila melanogaster* Meigen also has a low tolerance to desiccation, like most adult drosophilids (David *et al.* 1983, p.141; Walsh *et al.* 2011). Additionally, *D. melanogaster* appears to have responses to high temperatures that are very similar to those of *D. suzukii* (complete development to adults is only possible between 12 and 32°C; male sterility occurs at 30 °C, David *et al.* 1983). Nevertheless *D. melanogaster*

is not merely present in grape-growing regions of California, but is reported as a fruit pest (Bentley *et al.* 2009). This may indicate that *D. suzukii* has a similar potential.

- Damus' (2009) preliminary CLIMEX model, based on temperature and humidity, predicted that eastern Washington would be marginal in terms of *D. suzukii* survival because of its hot, dry climate. However, trapping carried out in eastern Washington in the summer and autumn of 2010 showed that high numbers of adults were caught in a variety of traps placed in tree fruit (Hansen 2011).
- Coyne *et al.* (1987) used three species of *Drosophila* (*pseudoobscura*, *melanogaster* and *simulans*) in Death Valley in California to test how far these species were able to disperse through desert environments. They found that released flies left oases and flew into the surrounding desert readily and also travelled from one oasis to another across many kilometres of desert. *D. pseudoobscura* was trapped in many remote desert locations as far as 26 km from the nearest likely breeding site.

### **Natural enemies**

A number of hymenopteran parasitoids have been reported in association with *Drosophila suzukii*, e.g.:

- *Pachycrepoideus vindemmiae* (Rondani) (Hymenoptera: Pteromalidae) was reared from *D. suzukii* pupae collected in the field in Oregon and British Columbia (Brown *et al.* 2011). This wasp has also been reported as a parasitoid of *D. melanogaster* (Noyes 2002). *P. vindemmiae* has been reported from New Zealand by Noyes (2002) and Boucek (1998), but is unlikely to be established. Valentine and Walker (1999) reported that it was introduced into New Zealand for biological control and released, but never established.
- *Asobara tabida* (Nees) and its sibling species *A. rufescens* Foerster (Hymenoptera: Braconidae) have been shown to be able to develop on *D. suzukii* in the field in Japan (Mitsui *et al.* 2007). *A. tabida* is recorded from New Zealand (Berry 2007).
- Species of the figitid genera *Ganaspis* and *Leptopilina* and the diapriid *Trichopria* are reported parasitoids of *D. suzukii* in Japan (Kimura & Anfora 2011). Species of *Leptopilina* and *Trichopria* are present in New Zealand and *Ganaspis* is probably also represented (Macfarlane *et al.* 2010, J. A. Berry, unpublished data).

Since known and potential *D. suzukii* parasitoids are already present in New Zealand, it is likely that some level of parasitism would occur. However significant population control is unlikely without host-specific control agents, because *D. suzukii* has a high dispersal capacity and reproductive rate. Even if a local population is exterminated, migrants would be likely to establish new populations.

### **Laboratory data on thermal tolerance**

There are some laboratory data available on the effect of temperatures on *Drosophila suzukii*. These data are useful for quarantine management but may have limited utility in predicting geographical distribution, because insects use a variety of strategies to deal with temperature stress in natural environments. In Japan, for example, *D. suzukii* has been found at localities with mean winter temperatures far below those that can be tolerated in the laboratory (see “Overwintering”), leading some authors to suggest that adults must overwinter in anthropogenically-protected sites, or migrate from southern Japan every year. Additionally, the basic biology of this species is incompletely known. Its recent introduction into new habitats and exposure to new selection pressures such as higher temperatures and new insecticides means that many phenotypes are likely evolving (Begun 2009).

### **Cold tolerance**

*D. suzukii* overwinters as adult flies (Kanzawa 1939) and it is assumed that this is the most cold-tolerant developmental stage. Kimura (2004) used adult flies reared at a constant



temperature (23°C) under a diapause-preventing long day regime. He found that 75% of adults were killed by 24 hours exposure to -1.6 or -1.8°C (geographical variation) for females and -0.7°C for males (Table 2).

**Table 2: *Drosophila suzukii* – Measured effect of temperature on adults from two regions after 24 hours (after Kimura 2004)**

	Cold			Heat		
	LT <sup>1</sup> <sub>25</sub>	LT <sub>50</sub>	LT <sub>75</sub>	LT <sub>25</sub>	LT <sub>50</sub>	LT <sub>75</sub>
Females (Sapporo)	-1.1°C	-1.6°C	-1.8°C	32.3°C	32.6°C	32.9°C
Males (Sapporo)	0.5°C	-0.1°C	-0.7°C	31.6°C	32.2°C	32.6°C
Females (Tokyo)	-0.5°C	-1.2°C	-1.6°C	32.4°C	32.7°C	33.3°C
Males (Tokyo)	0.3°C	-0.3°C	-0.7°C	31.8°C	32.3°C	32.6°C

<sup>1</sup>= Lethal temperature, LT<sub>25</sub> = temperature at which 25% of the population was killed  
Sample size = "two replicates, each with about 20 individuals of each sex"

Kanzawa (1939) carried out cold storage trials on *D. suzukii* eggs and larvae in cherries at -0.6 to 0.0°C; 0°C; 1.1°C and 1.7 to 2.2°C for varying lengths of time.

Bolda (2009) interpreted these results and concluded that “at constant temperatures of up to 35°F [1.7°C], 96 hours or more of cooling resulted in total mortality of spotted wing drosophila eggs and larvae”. However it is noted that “oviposition counts” appears to have been used in these experiments rather than eggs, and the numbers are relatively low (ranging from 9 to 83). Further testing of cold temperatures against eggs and larvae is underway in California which appears to support Kanzawa’s results, though no efficacy data is available as yet.

Kimura (2004) found little difference in thermal tolerance between cool and warm-temperate strains of *D. suzukii* and concluded that the capacity of *Drosophila* species to increase cold tolerance seems to be limited.

### Heat tolerance

Kimura (2004) found that under experimental conditions 75% of female *Drosophila suzukii* died at a constant temperature of 32.9 to 33.3°C (geographical variation) for 24 hours and males were slightly less tolerant (Table 2); Walsh (undated) reported that males become sterile at 30°C. Sasaki and Sato (1995b) reported that fifth generation eggs did not develop into adults in captivity under (presumably) ambient conditions in Japan with maximum daily temperatures above 35°C; and pupae did not emerge where maximum daily temperatures were above 32°C (Note: n = 4 insects). Walton *et al.* (2010b) stated that “adults die at 35°C treatment for 3 hours and the reproduction rate is reduced between 30°C and 35°C” (the number of flies treated is not known).

## Monitoring

Although some trapping protocols exist (*e.g.* Skinkis 2009), there are as yet no efficient detection or monitoring tools for *Drosophila suzukii* (Cini *et al.* 2012). It is not known whether this species produces pheromones to attract mates; no specific pheromone lures are currently available for use in detection (Walsh *et al.* 2011). While *D. melanogaster* and other drosophilids can complete all life stages on the same fermenting materials, gravid *D. suzukii* females need to find undamaged ripening fruits for oviposition. It is therefore likely that the odour produced by fermenting fruits represents a generic food cue to *D. suzukii*, whereas egg-laying females target volatiles from fresh fruits specifically (Cini *et al.* 2012).

Various fruits or fruit derivatives were initially tested for trapping, including:

- a mixture of brown sugar, alcohol, vinegar and water (Wu *et al.* 2007)
- ripe bananas, strawberry puree, apple cider or a yeast/sugar/water mix (OSU 2009a)

- apple cider vinegar (ACV) (EPPO factsheet 2010)
- baker's yeast and sugar dissolved in water (BCMAL 2010a).

Current recommended monitoring recommends the use of ACV or sweet white wine and adjacent yellow sticky traps (Skinkis 2009).

*Trap efficacy:* there are various reports that trap catches do not reflect the number of flies in orchards, e.g. BCMAL (2010b). Kleiber *et al.* (2011) reported that the current trapping method is not effective for monitoring low level infestation, and that growers may still experience low levels of fruit infestation in the absence of trap captures. Wilson (2011) concluded that ACV trapping alone is not an indication of infestation. OSU (2010a) noted reports of larvae-infested fruit near traps that had little or no catches, e.g. infestation in cherry fruit in an orchard with an adjacent trap that had no catches; likely infestations in three strawberry crops with traps that had no catches located in the field. Langellotto (2010) suggested various explanations for traps not catching flies where fruit damage is found, including poor trap placement, failure to follow trapping protocols, and the possibility that the presence of large quantities of ripe fruit may overwhelm bait attractiveness.

*Future directions:* ongoing research is being conducted to identify a defined attractant with increased sensitivity to monitor the presence and population density of SWD:

- Landolt *et al.* (2012) showed that SWD are attracted to vinegar and wine, and more attracted to a combination of the two, indicating a synergy of the two materials.
- Kleiber *et al.* (2011) found that many compounds are as attractive to SWD as the current ACV lure. Compounds tested included rice vinegar, seasoned rice vinegar, soy sauce, *Drosophila* lure, Insect Bait and Nulure<sup>12</sup>. *Drosophila* lure and Insect Bait were considerably more attractive than the other baits. These workers varied the proportions of acetic acid and ethanol in traps. Lower levels of acetic acid were found to attract more flies than higher levels (2% to 6%), while no difference in attraction was found when ethanol concentration was varied between 5 and 25%.
- Kleiber *et al.* (2011) also tested whether there was a preferred entry to traps, and found no significant difference.

Yeast lures are also being tested. Burrack (2011) compared ACV and yeast lures, and ACV was found to be more efficient generally. However Isaacs *et al.* (2011) found yeast-baited traps outperformed ACV in terms of numbers of SWD flies caught and date of first capture. Ohm and Dreve (2011)<sup>13</sup> found that yeast tends to be more attractive than ACV in the months when SWD is most abundant in traps. They alternated ACV and yeast traps throughout a 6-acre blueberry field and found that SWD preferred yeast from June through the fall, with their preference switching to ACV on 17 November 2010 when temperatures began to come down (the first freeze of the year was on 21 November 10). This suggests the attractiveness of the yeast is temperature dependent, and requires relatively warm temperatures to become activated.

Since some species of *Drosophila* (e.g. *D. melanogaster*) are known to prefer and cultivate specific yeast species, it is possible that SWD may be attracted to specific yeasts. If so, these yeast species could be used to improve bait lures. Hamby (2011) compared the yeast fauna of three varieties of SWD-infested raspberries to that of uninfected berries, and also isolated yeasts from the midgut and frass of SWD. One species, *Hanseniaspora uvarum*, was found to be more common than others.

Wu *et al.* (2007) found that the effectiveness of a brown sugar/alcohol/vinegar lure was enhanced when hung near a red ball. This was supported by Kleiber *et al.* (2011), who tested

<sup>12</sup> The *Drosophila* lure is an experimental *D. melanogaster* attractant, Insect bait and Nulure are insecticide adjuvants, control was soap water.

<sup>13</sup> A. Ohm pers. comm. 7 Dec 2011.

different colours (black, clear, orange, red and white) for attraction to SWD over two years. They found that attractiveness varied each year, but in both years red traps caught more flies and clear traps caught the least.

## Pathway descriptions

The purpose of this report is to assess the risks associated with *Drosophila suzukii* entering New Zealand via fresh produce imports from the United States of America. The affected pathways include the existing trade in apricots, cherries, peaches, plums (and their interspecific hybrids, such as pluots and plumcots), nectarines, strawberries and table grapes. A potential affected pathway is blueberries, a current market access request from the USA.

The following section describing host status and impacts for each commodity in the native and invasive ranges of the fly provides basic information to inform the “likelihood of entry” and impact assessments. This information is summarised in Table 4 (*Likelihood of entry on a commodity-specific basis*) and some regarding impacts on various crops is also used in Table 5 (*Summary of reported impacts on selected crops*).

### Apricots (*Prunus armeniaca*)

Apricots are an approved commodity from the USA. However there were no importations into New Zealand between 1 April 2010 and 31 March 2011<sup>14</sup>. In previous years, small volumes of apricots have been imported from the USA between May and August, i.e. during late autumn and winter.

Apricots are not widely reported as hosts in the native range of *D. suzukii*. Kanzawa (1935, 1939) reported only a few adults emerging from damaged or dropped apricots collected in the field and did not report any emergences from whole, growing fruit.

Reports of damage in the fly’s introduced range appear to be relatively rare but may be building slowly. Coates (2009) reported that, with the exception of very late, over-ripe or damaged fruit, no apricots in commercial orchards in California were attacked, even when located near infested cherries. Acheampong (2010a) stated that *D. suzukii* “feed on” apricots; presumably this is to distinguish this host from breeding hosts. Van Steenwyk (2010) reported apricot (and tomato) as “Not hosts at this time”.

However :

- Shearer *et al.* (2010) reported “larval contamination in commercial peach, apricot, cherry” in British Columbia.
- EPPO (2010e) reported it as “officially identified in June 2010 on ... apricot in Corsica”.
- Bush and Bell (2011) give control measures for commercial apricots in the Pacific Northwest.
- Grassi *et al.* (2011) reported that in Italy (August 2010), 20 to 50% of apricots sampled from orchards located in cherry production districts were infested with *D. suzukii* eggs. Hard and unripe (green/orange) fruit were infested as well as ripe and overripe, fallen fruit.
- EPPO (2010f) considered apricots to be “major hosts” (without supporting data).

Other “apricot” species, e.g., Japanese apricots (*Prunus mume*) have been reported as hosts. Hauser and Damus (2009) and Acheampong (2010a) listed ripe Japanese apricots as hosts in Asia.

*Summary: Apricots do not appear to be favoured hosts for Drosophila suzukii. There are few reports of damage from its native range; however reports from some parts of its introduced range appear to be collecting slowly.*

<sup>14</sup> Source: Cath Kingston, Analysis and Profiling Group; Verification, Risk and Support Directorate, Ministry of Agriculture and Forestry

### **Blueberries (*Vaccinium* spp.)**

Blueberries, although not currently approved for importation from the USA, are an important host in the USA; accordingly this pathway is examined here. Blueberries would be likely to be imported from April to November (pers. comm., B. McDonald, Border Standards, MPI). In the original studies on *D. suzukii* in its native range (e.g. Kanzawa 1935, 1939), blueberries were not reported as hosts. However Sasaki & Sato (1995c) reported rearing many adult flies from ripe field-collected blueberries in Japan, which they stated to be a new host record. Mitsui *et al.* (2010) also reared flies from fallen "*Vaccinium* spp." fruit collected at high altitude in Japan, and Uchino (2005) also reported damage to blueberries in Japan. In its introduced range, *D. suzukii* has been reported as a confirmed finding in blueberries from California (Bolda 2009), Oregon (ODA 2010a, OSU 2009a), Florida (FDACS 2010), British Columbia (BCMAL 2009) and from Europe (EPPO 2010a). Blueberries are reported as a "most preferred" host by OSU (2010b).

*Impact:* *D. suzukii* has been confirmed attacking fruit on commercial *Vaccinium* (blueberry) plants in Florida, where it is said to have the potential for rapid build-up of populations (FDACS 2010), and EPPO factsheet (2010) reports significant economic damage to this crop. Two blueberry fields were surveyed in early October in Oregon and one showed no damage at all while the other showed about 20% infestation (OSU 2009b). Walsh *et al.* (2011) considered that blueberry crops were a primary concern in the Pacific Northwest and California. Damage to blueberry crops is reported from Italy (EPPO 2010a). BCMAL (2010b) strongly recommend that protective sprays be applied to berries in British Columbia to prevent fruit infestation.

According to CFIA (2010) there are recent reports of outbreaks in Chiba and Aomori on blueberries, and this fly is considered an economic pest of this crop throughout Japan. Tamada (2009) states that *D. suzukii* is regarded as the "most widespread troublesome insect pest" of blueberries in Japan, and according to ODA (2010a) it has been reported as a significant pest of blueberries in China. Bolda *et al.* (2010) reported maximum yield losses for blueberry crops in the USA at 40%.

*Summary:* *Blueberries are favoured hosts for Drosophila suzukii. There are recent reports of significant economic damage to this crop in parts of its native range (Japan and China) and it has been reported attacking fruit on commercial blueberry plants in the USA.*

### **Cherry (*Prunus avium*)**

Cherries are an approved commodity from the USA. Between 1 April 2010 and 31 March 2011 a total of 165, 510 kg were imported, the majority from California with smaller volumes were also received from Oregon and Washington (see Table 3). Cherries are imported from the USA between May and August, *i.e.* during late autumn and winter.

The original description of *Drosophila suzukii* was based on flies infesting cherries in Japan (initial reports were from Yamanashi Prefecture in 1916; Kanzawa 1935). Kanzawa (1939) reported many adults emerged from whole fruit collected in the wild in Japan, and considered cherry to be a favoured host. When peaches, plums and cherries were offered as choices, oviposition rates were very high on cherries. The oviposition rate on peaches was 27% of that on cherries; the oviposition rate on plums was 9% of that on cherries (Kanzawa 1939). Cherries have also been confirmed as hosts in Oregon (Dreves *et al.* 2009, ODA 2010a), California (Coates 2010); British Columbia (Shearer *et al.* 2010) and in Europe (EPPO 2010b). OSU (2010b) reported cherries as a "most preferred" host.

*D. suzukii* is able to infest healthy cherry fruits attached to the tree. Kanzawa (1935) recorded oviposition into undamaged fruit that had started to "colour and sweeten but are not fully ripe yet". Although most eggs were laid into fully ripe cherries, a "rather large number" were also

laid in slightly unripe cherries. When eggs were laid into unripe fruit, flies did not successfully complete development. Most eggs were laid and development was seen in cherries that were three days prior to being fully ripe, *i.e.* cherries that were ripe enough to be harvested for market. Coates (2010) reported that susceptibility varied with cherry variety, with Black Tartarian and Early Burlat very susceptible; Rainier susceptible and Bing moderately susceptible (California: San Benito, Santa Cruz, Santa Clara and Monterey Counties).

*Impact:* Kanzawa (1939) reported that the crop that sustained the most damage in Japan was cherries (along with grapes), and impacts on cherry crops are widely reported in both the native and introduced ranges of the fly. Kanzawa (1935, Japan) surveyed orchards in 1931/1932 and reported that 5 % to 80 % of fruit was damaged. Kanzawa (1939) reported that 7 % to 75% of fruit on trees was damaged, and 0 to 55 % of harvested fruit was infested.

High levels of damage are also reported from the introduced range of *D. suzukii*. EPPO (2010b) reported significant damage in France. Shearer *et al.* (2010) reported a \$500 million loss (30 to 40% of the crop in California, 2008) due to *D. suzukii* damage, mainly in cherries, and also larval contamination in commercial sweet cherries in British Columbia, with “unconfirmed reports of 0.5 million kg cherries diverted to internal markets”. OSU (2009b) reported that California lost about one-third of its cherry crop from Davis to Modesto. ODA (2010a) reported severe damage to cherries, with infestation rates of up to 80% of the crop reported in one locality. Coates (2010) reported minimal to near 100% damage to sweet cherries in California depending on variety.

Walsh *et al.* (2011) considered that cherry crops were a primary concern in the Pacific Northwest and California, and BCMAL (2010b) strongly recommend that protective sprays be applied to late cherries in British Columbia to prevent fruit infestation.

In Italy over 90% of late-harvested cherries in some orchards were infested, even when the insecticides phosmet and acetamiprid had been sprayed at the reddening of the fruit for *Rhagoletis cerasi* control.

*Summary: Sweet cherries appear to be a favoured host for Drosophila suzukii both in its native range and in commercially produced fruit in recently invaded areas such as North America and Europe. Rates of fruit damage ranging from minimal to near 100% have been reported. Damage appears to vary depending on fruit variety.*

### **Grapes (*Vitis vinifera* and hybrids)**

Grapes are an approved commodity from the USA. Between 1 April 2010 and 31 March 2011 approximately 6,711,600 kg were imported; the majority from California but a small volume was also received from Arizona (see Table 3). Grapes are imported from the USA between June and January, *i.e.*, during winter, spring and early summer.

There is debate over the host status of grapes. In initial studies carried out in Japan, Kanzawa (1935) stated that *D. suzukii* infests “perfect” fruit, and that some varieties of grapes were badly damaged. Kanzawa (1939) confirmed that wild-collected, undamaged (whole) grapes were hosts, and that adult emergence was variety-dependent. Many adults emerged from: Black Hamburg, Gros Coleman, Golden Queen, Muscat of Alexandria and Muscat Hamburg. Few adults emerged from: Herbert and Foster’s Seedling varieties. In some cultivars (the examples given were Kosshu and Delaware), Kanzawa (1939) suggested that the skin was too tough for the female to insert her ovipositor. Kanzawa (1935) carried out laboratory studies on oviposition in cherries and grapes and found females laid  $161.1 \pm 23.9$  eggs over a lifetime on cherries ( $n = 17$ ) and  $105.8 \pm 15.8$  eggs on Concord grapes ( $n = 17$ )<sup>15</sup>.

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<sup>15</sup> Reported by Lee *et al.* (2011c)

In the fly's introduced range (mainland USA), Dreves *et al.* (2009) reported grapes as a “confirmed finding” and OSU (2010b) reported them as a “most preferred” host. Walton *et al.* (2010a) stated that *D. suzukii* is able to infest undamaged [grape] berries, and OSU (2009b) reported that adult flies emerged from wine grapes and red table grapes collected in the Willamette Valley. In British Columbia, infestations of *Vitis* spp. were confirmed in 2009 (BCMAL 2009). BCMA (2011) described *D. suzukii* as an “aggressive pest” of table grapes (and perhaps wine grapes<sup>16</sup>), and gave guidelines for its management in commercial crops in BC, including a list of emergency chemical registrations. Maiguashca *et al.* (2010) reported on research on the host status of grapes in Washington in 2010. They found that:

- flies were unable to oviposit on undamaged Syrah grapes in no-choice field tests carried out early in the season,
- flies consistently oviposited on injured and uninjured ripe California seedless grapes (Red Flame, used as controls) and adults emerged successfully in no-choice lab tests
- very little oviposition or successful emergence of adults was observed from undamaged wine grapes (“Early Campbell”, Merlot and Riesling) from Washington in no-choice lab tests. Greater oviposition and adult emergence rates occurred when fruit of these varieties was damaged. However, the trials indicated that these varieties may become better hosts when sugar levels in the fruit increased with fruit maturity.

Lee *et al.* (2011b) reported similar results: oviposition was observed through the intact skin as well as the junction between the pedicel and grape if it was broken. They calculated the ‘percent development’ (total number of developing *D. suzukii*/total number of eggs laid within a replicate) on various wine grape cultivars, and found it varied from 0 to  $9.2 \pm 6.0\%$ . Substantially fewer flies were caught in traps in grapes than in traps in other tree fruit crops (Hansen 2011).

The EPPO expert working group did not consider that grapes could be regarded to be a major host, but conceded uncertainty over this point (EPPO 2010e, f). Recent reports on host status in Italy are somewhat contradictory. Grassi *et al.* (2011) reported that while adults were caught in vineyards in Italy, eggs and larvae were detected in autumn only on over-ripe bunches of wine grapes; however Cini *et al.* (2012) cited recent observations of grapes as field hosts in Northern Italy, with soft skinned varieties being more affected.

*Impacts:* Serious damage and economic impacts on grapes have been reported in the native range of *D. suzukii*. Kanzawa (1935) reported that “grapes ... grown out in the open without bags over them had been completely wiped out” in the Akayu region of Japan<sup>17</sup>. According to Kanzawa (1939), the most pronounced damage caused by *D. suzukii* in Japan was to cherries and grapes. Kanzawa (1939) reported that in the Akayu region, 70–80 % of harvested Black Hamburg grapes were damaged by *D. suzukii* when the usual practice of bagging fruit was delayed. CFIA (2010) reported recent outbreaks on grapes in Hokkaido, and stated that *D. suzukii* is currently considered an economic pest of both grapes and blueberries throughout Japan.

As yet, there are few reports of significant damage in the introduced range. OSU (2009b) reported that no noticeable damage was found in harvested wine and red table grapes, despite confirmed *D. suzukii* infestations. However Cowles (2011) reported that “many” wine grapes were lost in Connecticut and Rhode Island (Northeastern USA) in 2011 and that “grape growers have seen 20–50% loss of grapes due to sour rot caused by SWD infestation”. It is unclear whether losses due to secondary infestation relate to a similar level of fly infestation. Walsh *et al.* (2011) considered damage to wine and juice grape crops from *D. suzukii* to be a primary concern in the Pacific Northwest and California.

<sup>16</sup> BCMA (2011) stated “SWD’s effect on wine grapes is not currently known, but research is ongoing”.

<sup>17</sup> It is not entirely clear from the translation whether this damage was considered to be caused by *D. suzukii* alone

*Summary: Field infestation of undamaged grape berries has been confirmed by numerous sources. Preference is based on grape variety, with thinner skinned, sweeter and less acidic varieties appearing to be the most preferred, and wine grapes appearing to be particularly poor hosts. In Japan serious damage and economic impacts have been reported in the past and there are also recent reports of outbreaks; however economic impact in recently invaded areas does not appear to be high at present.*

### **Peaches (*Prunus persica*)**

Peaches are approved commodities from the USA. Between 1 April 2010 and 31 March 2011 approximately 2,052,290 kg of peaches and nectarines were imported from California (see Table 3). Peaches are imported from the USA between May and November, *i.e.* during late autumn, winter and spring.

In its native range, Kanzawa (1935) reported ripe and fallen fruit as hosts of *D. suzukii* in Japan; while Kanzawa (1939) reported only that many adults emerged from damaged or dropped fruit collected in the field, and from unripe and ripe cut fruit in the laboratory. Sasaki & Sato (1995c) confirmed that healthy peach fruit is infested in Japan. In recently invaded areas, Coates (2009) reported that soft, tree ripe peaches were hosts in commercial orchards in California, ODA (2010a) reported that infested peaches were found in Oregon and Shearer *et al.* (2010) reported larval contamination in commercial peaches in British Columbia. BCMA (2011) described *D. suzukii* as an “aggressive pest” of stonefruits, and gave guidelines for its management in commercial crops in BC, including a list of emergency chemical registrations. EPPO (2010e) reported *D. suzukii* as “officially identified in June 2010 on ... peach ... in Corsica”.

OSU (2010b) reported peach as a “most preferred” host, while Kanzawa (1939) reported it to be less attractive than sweet and flowering cherries, but more attractive than plums and apricots when fresh and undamaged. When peaches, plums and cherries were offered as choices, oviposition on peaches was only 27% of that on cherries (Kanzawa 1939).

*Impact:* EPPO (factsheet 2010) reports significant economic damage to peaches, and a media report (CPAN 2009) mentioned destruction of 20% of Elberta peaches in an Oregon orchard in 2009. OSU (2009b) reported that “Willamette Valley peach growers were hit hard, especially in the late season, with losses [due to *D. suzukii*] up to 80 percent in some orchards”. No information has been found indicating a preference for particular peach varieties (excluding nectarines, see below). Walsh *et al.* (2011) considered that peach crops were a primary concern in the Pacific Northwest and California and BCMAL (2010b) strongly recommends that protective sprays be applied to peaches in British Columbia to prevent infestation.

*Summary: Peaches are reported as favoured hosts and commercial peaches have incurred significant economic damage in the USA despite there being few reports of damage to peaches in the fly’s native range.*

### **Nectarines (*Prunus persica* var. *nucipersica*)**

Nectarines are approved commodities from the USA. Between 1 April 2010 and 31 March 2011 approximately 2,052,290 kg of peaches and nectarines were imported from California (see Table 3). Nectarines are imported from the USA between May and November, *i.e.* during late autumn, winter and spring.

There are no reports of nectarines as hosts of *D. suzukii* in its native range from the original (*e.g.* Kanzawa 1935, 1939) or more recent publications (*e.g.* Sasaki & Sato 1995b, c). In its introduced range, there are reports of nectarines being hosts in California (Hauser & Damus 2009) and British Columbia (BCMAL 2010b). In the USA, while peaches are considered a preferred host, nectarines, are stated to be “other” hosts (OSU 2010b). Although BCMAL

(2010b) strongly recommends spraying nectarines to prevent infestation, there are few reports of serious damage to nectarine crops.

*Summary: Nectarines are not reported as hosts of D. suzukii in its native range. In its introduced range, nectarines are reported as hosts, but do not currently appear to have caused serious damage to commercial crops.*

### **Plums (*Prunus domestica* and hybrids)**

Plums and plum hybrids are approved commodities from the USA. Between 1 April 2010 and 31 March 2011 approximately 706,565 kg were imported from California (see Table 3). Plums and plum hybrids are imported from the USA from June to November, *i.e.* during winter and spring.

According to Kanzawa (1939), *D. suzukii* is able to oviposit into and complete development in fresh, undamaged whole plums, but other fruit were found to be preferable. According to his study, carried out in Japan:

- healthy plums were less attractive than sweet and flowering cherries and peaches but more so than apricot
- few adults emerged from whole Terada plums collected in the field and many emerged from overripe and cut Terada and White Beauty plums reared in the lab
- when peaches, plums and cherries were offered as choices, oviposition rates on plum were only 9% of those on cherries.

Reports from plums in the fly's introduced range are contradictory; however, they also indicate that host status varies with variety or hybrid. Hauser and Damus (2009) recorded Asian plums, plums, plumcots and Satsyma [sic] plums as hosts in California. Plums are reported as a "confirmed finding" by Dreves *et al.* (2009). Shearer *et al.* (2010) reported *Prunus domestica* and "plums of many kinds", Asian plums, plumcots and Satsuma plums as hosts in California. Van Steenwyk (2010) reported that plum was only as a "weak" laboratory host; and according to OSU (2010b) plums and plumcots are considered "other" (as opposed to "preferred") hosts in the USA.

*Impact:* Coates (2009) reported 100% damage to pluots in California, and EPPO factsheet (2010) reports significant economic damage to plums. Shearer *et al.* (2010) reported damage to plums in Oregon in 2009 and 2010. BCMAL (2010b) strongly recommend that protective sprays be applied to plums in British Columbia to prevent fruit infestation.

*Summary: Although D. suzukii is clearly able to complete development in healthy ripe undamaged plum fruit, plums and some plum hybrids do not appear to be preferred hosts. There are few reports of significant economic damage in either the fly's native or the invasive range, with the exception of pluots in California.*

### **Strawberries (*Fragaria ananassa*)**

Strawberries are an approved commodity from the USA. Between 1 April 2010 and 31 March 2011 approximately 93,619 kg were imported from the USA (see Table 3). Strawberries are imported from the USA from February to July *i.e.* during late summer, autumn and winter. Strawberries appear to be a favoured host throughout the range of *D. suzukii*. The first detected *D. suzukii* incursion in North America was on strawberries and caneberries in California in August 2008 (Bolda *et al.* 2010). In initial studies in Japan, Kanzawa (1935) reported "perfect fruit" as hosts and Kanzawa (1939) reported many adults emerging from whole fruit collected in the wild. In the USA, strawberries are reported as a "most preferred" host (OSU 2010b). *D. suzukii* has been reported infesting strawberries in California (Bolda 2009), Oregon (OSU 2009b), Washington (Walsh *et al.* 2011), North Carolina (Burrack 2010), Florida (confirmed attacking fruit on commercial strawberry plants, FDACS 2010), Italy (EPPO 2010a) and France (EPPO 2010b).



*Impact:* Although Walsh *et al.* (2011) reported that strawberry crops were a primary concern in the Pacific Northwest and California, US reports of losses for this crop vary by location and end use. Yield losses of 20% were reported in Oregon, while in California relatively little economic damage has been observed to date (Bolda *et al.* 2010), possibly because of the short time between harvests of strawberries for the fresh market in California. Because there is a longer harvest interval for processing strawberries (*e.g.*, freezing, jams, jellies), yield losses may be greater for this market segment (Bolda *et al.* 2010). EPPO (factsheet, 2010) reported significant economic damage to strawberries. Cowles (2011) reported that in the northeastern USA, growers of day-neutral strawberries “are looking at complete crop loss from mid-September to the end of harvest”.

*Summary:* Strawberries are favoured hosts for *Drosophila suzukii*. Losses for this crop vary by location and end use, with reports of moderate damage in the Pacific North West and potentially severe damage in the northeastern USA.

**Table 3: Volumes (kg) of risk commodities imported into New Zealand from the USA (1 April 2010 and 31 March 2011)<sup>1</sup>**

Commodity	Arizona	California	Hawaii	Oregon	Washington	Unknown	Total
Cherry		104,073		7,521	27,088	26,828	165,510
Grape	3,198	6,506,959	1			201,449	6,711,607
Nectarine		958,075				29,719	987,794
Peach		314,163				2,754	316,917
Peach/Nectarine		747,579					747,579
Plum		358,319				3,375	361,694
Plum, European		222,000					222,000
Pluot		122,872					122,872
Strawberry		87,906				5,713	93,619
Total	3,198	9,421,946	1	7,521	27,088	269,838	9,729,592

<sup>1</sup>Source: C. Kingston, Verification, Analysis and Profiling Group, MPI

## Entry assessment

The likelihood of entry will be discussed in general terms and then assessed specifically for each pathway using information from the pathway descriptions above. Once *D. suzukii* has entered New Zealand on the fresh produce pathway, the likelihood of exposure is expected to be relatively independent of the commodity association, and the likelihood and consequences of establishment are expected to be completely independent of the commodity association. Therefore, separate pathways are discussed only in relation to entry likelihood.

*Drosophila suzukii* has not been identified in interceptions at the New Zealand border (see “Interceptions”), however interceptions of other *Drosophila* species and unidentified “*Drosophila* sp.” are relatively common. All stages including adults have been detected alive at the border on a variety of fresh produce (including hosts of *D. suzukii*) air and sea-freighted from many countries, including the USA.

Eggs, larvae and pupae may be present inside fruit. Eggs are small and inconspicuously coloured (average 0.62 x 0.18 mm wide; Kanzawa 1939). Oviposition scars are described as small or very small (EPPO 2010a, ODA 2010a respectively). Eggs are difficult to detect in fruit (ODA 2010a) and fruit containing recently oviposited eggs are not easily distinguished from undamaged fruit (CFIA 2010).

Larvae are also small and difficult to detect inside fruit, especially in early stages of attack or in low numbers (ODA 2010a, EPPO 2010a, Burrack 2011). According to EPPO (2010a), infested fruit are likely to be traded undetected. ODA (2010a) states “Because egg laying occurs near harvest and early symptoms are subtle, it is very easy for infested fruit to be transported undetected”.

Although adults are mobile and likely to move off fruit during harvesting and processing, interception data indicates that entry of adults cannot be completely ruled out. Their presence may be as a result of attraction to fruit in packhouses or from pupae emerging in transit.

Although drosophilids are sensitive to desiccation (USU 2009), live *Drosophila* of other species (all life stages) are clearly able to survive existing transit conditions for fresh produce from the USA and other countries. *D. suzukii* overwinter as adults (Kanzawa 1939), and may be able to survive long term cold storage as adults, depending on the conditions.

*Summary:* *D. suzukii* may enter New Zealand as adult flies associated with fruit, or as eggs, larvae or pupae within fruit. The life stages that are most likely to enter the country are eggs or early instar larvae; late instar larvae may enter if there are few in the fruit, and the damage caused is not conspicuous enough to be detected during fruit sorting for commercial quality control. The likelihood of entry on a commodity-specific basis is summarised in Table 4.

**Table 4: *Drosophila suzukii* – Likelihood of entry on a US commodity-specific basis**

Commodity	Summary (host status and levels of infestation)	Likelihood of entry	Season <sup>18</sup>	Volume imported <sup>19</sup>
<b>Apricots</b> ( <i>Prunus armeniaca</i> )	Apricots do not appear to be favoured hosts. There are few reports of apricots as hosts from the native range of the fly; however reports from some parts of its introduced range appear to be collecting slowly. In Italy in 2010, 20 to 50% of apricots in orchards located in cherry production districts were infested with <i>D. suzukii</i> eggs. Hard and unripe (green/orange) fruit were infested as well as ripe and overripe, fallen fruit.	LOW TO MODERATE	May to August	NIL
<b>Blueberries</b> ( <i>Vaccinium</i> spp.)	Blueberries are favoured hosts. There are recent reports of significant economic damage to this crop in parts of its native range (Japan and China) and it has been reported attacking fruit on commercial blueberry plants in the USA.	HIGH	April to November	NIL
<b>Cherries</b> ( <i>Prunus avium</i> )	Sweet cherries appear to be favoured hosts both in the fly's native range and in recently invaded areas such as North America and Europe. Rates of fruit damage ranging from minimal to near 100% have been reported. Damage appears to vary depending on fruit variety.	HIGH	May to August	165,510 kg
<b>Grapes</b> ( <i>Vitis vinifera</i> )	Although there is some debate about the host status of grapes, infestation of undamaged fruit in the field is confirmed by a number of sources. Some varieties appear to be more favoured, with thinner skinned, sweeter and less acidic varieties appearing to be preferred. In Japan serious damage and economic impacts have been reported in the past and there are also recent reports of outbreaks; however economic impact in recently invaded areas does not appear to be high at present.	UNCERTAIN	June to January	6,711,607 kg
<b>Peaches/ nectarines</b> ( <i>Prunus persica</i> / <i>Prunus persica</i> var. <i>nucipersica</i> )	Peaches are reported as favoured hosts and have incurred significant economic damage in the USA despite there being few reports of damage in the fly's native range. Although nectarines are reported hosts there are few reports of serious damage.	HIGH	May to November	2,052,290 kg
<b>Plums</b> ( <i>Prunus domestica</i> and hybrids)	Although <i>D. suzukii</i> is clearly able to complete development in healthy ripe undamaged plum fruit, plums and some plum hybrids do not appear to be favoured hosts. There are few reports of significant	HIGH for some hybrids	June to November	706,566 kg

<sup>18</sup> Data for three seasons (2008-2011)

<sup>19</sup> 1 April 2010 to 31 March 2011. Season and volume data supplied by Cath Kingston, Analysis and Profiling Group; Verification, Risk and Support Directorate, Ministry of Agriculture and Forestry

Commodity	Summary (host status and levels of infestation)	Likelihood of entry	Season <sup>18</sup>	Volume imported <sup>19</sup>
	economic damage in either the fly's native or the invasive range, with the exception of pluots in California.			
<b>Strawberries</b> ( <i>Fragaria ananassa</i> )	Strawberries are favoured hosts. Losses for this crop vary by location and end use, with reports of moderate damage in the Pacific Northwest.	HIGH	February to July	93,619 kg

## Exposure assessment

For successful exposure to occur, adult flies must find feeding hosts (dropped or damaged fruit, plant sap). Adults are very mobile and may be exposed to suitable hosts at almost any point in the distribution pathway.

For other life stages within fruit, successful exposure requires development to continue until adult emergence and subsequent location of feeding hosts. Therefore, the host must remain in a condition suitable for supporting the development of larvae. Like most tephritid fruit flies, *D. suzukii* larvae can leave their host and pupate in the substrate (*e.g.* soil). However, they can also pupate within the host (as can some tephritids), which means that larvae or pupae that entered the country within fruit could potentially emerge and leave the distribution pathway at any point, in the same way as flies that enter the country as adults.

Fruit infested with larvae or pupae is unlikely to be completely consumed and very likely to be discarded. The likelihood of exposure is dependent on the method of fruit disposal. Most domestic disposal appears to be by very low risk methods – almost 85% of household organic waste in New Zealand is via landfill or in-sink disposal into sewage. Only around 13% of household organic waste is composted (Hogg *et al.* 2010). This is considered to be a comparatively high risk disposal method, for example Acheampong (2010b) states “*Do not compost infested fruit as home composting will not kill flies*”. The proportion of composted material that is both imported and infested with risk organisms is likely to be extremely low. However, the amount of household organic waste is surprisingly large. The amount disposed of by composting can be calculated (approximately 13% of around 248 kg of food waste per year, or about 20 kg per household; figures from Hogg *et al.* 2010). Additionally, Viggers (1993) estimated that in any week about 7.5% of the population over 12 years old was likely to drop fruit waste on roadsides or on the ground in New Zealand. This was classified as a high risk disposal method.

There is little information available regarding industry pathways and practices, such as the disposal of culled and unsold fruit by wholesalers and retailers. Disposal of fruit in cull piles is considered to be a high risk practice, for example Acheampong (2010b) states “*Flies will emerge from culls on the ground, cull piles and compost heaps to cause further damage to unharvested host fruit*”.

Risk material imported from United States is likely to enter New Zealand at most times of the year, with most arriving during winter months. Strawberries arrive from February to July, stonefruit from May to November at the latest, and grapes from June to January (Table 4). Blueberries would be likely to be imported from April to November.

A wide range of documented feeding hosts are common throughout New Zealand in commercial and backyard situations. Since *D. suzukii* overwinter as adults, flies emerging in winter are likely to be able to survive until conditions are suitable for breeding.

*The likelihood of exposure is considered to be high for adults and moderate for eggs and larvae.*

## Establishment assessment

Live adult drosophilids have been detected at the New Zealand border; theoretically one mated female could found a population.

Eggs and larval stages: for establishment to take place, adults of both sexes must emerge, and must then mate and locate host plants. It is not known whether these flies must locate a suitable oviposition host before mating will occur, as is the case with *Rhagoletis* species. It is not known if *D. suzukii* uses pheromones to attract mates; no specific pheromone lures are currently available for use in detection. In some tephritids the odour of ripening fruit attracts both sexes. It is likely that this also occurs in drosophilids because traps baited with mashed ripe bananas or strawberry puree are effective lures.

The likelihood of mating and subsequent establishment is considered to be higher for gregarious<sup>20</sup> insects than for solitary species (Yamamura & Katsumata 1999). *D. suzukii* would be considered relatively gregarious – although a record of 62 adults have been reported to emerge from a single cherry, the average number of eggs per cherry laid by a single female was found to be 2.7.

Since flies must oviposit in host fruit, a suitable number and species of host must be available before adults die. Adult *D. suzukii* overwinter as adults, so flies emerging in winter are likely to be able to survive until conditions are suitable for breeding.

A wide range of documented hosts are common throughout New Zealand in commercial and backyard situations, and additionally a number of other plants (*e.g.* wild rose, crab apple, flowering cherry) that may serve as alternate hosts and that ripen at different times throughout the year. In addition, adult *D. suzukii* have been observed in the upper reaches of trees and ovipositing in some species of flowers in the absence of preferred hosts (Walsh *et al.* 2011). Mitsui *et al.* (2010) found that *D. suzukii* bred on *Styrax* flowers at the end of May and the start of June, when the fruiting season of wild *Prunus* starts.

Developmental data and the existing distribution of this species suggest that ecologically most places in New Zealand will be suitable for establishment *D. suzukii*. Lower developmental thresholds have been calculated for various stages and the lowest reported is 8.4°C (Sasaki & Sato 1995b). Species with similar or higher developmental zeros have been able to establish in many growing areas in New Zealand and become serious pests *e.g.* *Cydia pomonella* and *Pieris rapae* (both 10°C; NAPPFAST Insect Development Database). *Drosophila melanogaster* and *D. simulans* Sturtevant, both with developmental zeros around 9.8°C (David *et al.* 1983) are established in New Zealand.

Preliminary results from Climex/Maxent modelling studies indicated that *D. suzukii* has the potential to establish along the west coast of USA and Canada (*e.g.* British Columbia), and in large parts of Eastern USA (Damus 2009). Parts of the Pacific Northwest have very similar climates in terms of temperature and rainfall to many growing areas in New Zealand.

*Spread:* Lee (2011a) carried out mark-recapture experiments in strawberries and found that most SWD were caught at the point of release, or up to 5m away. A few flies dispersed up to 87m (however, less than 2% of marked flies were recaptured). Adults can be blown by wind to nearby locations; however long distance dispersal is expected to be achieved by transportation of infested fruit to new regions. In Europe, Calabria *et al.* (2010) reported a spread of 1400 km in one year, presumably passively through infested fruits. Non fruit-bearing plants are not considered to be of significant risk in transporting this species (BCMAL 2009).

*The overall likelihood of establishment and spread is estimated to be high.*

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<sup>20</sup> Yamamura & Katsumata (1999) used the term “gregarious” to mean having an aggregated distribution

## Consequence assessment

### Economic consequences

*D. suzukii* attacks intact ripe fruit and has a range of hosts that are economically important in New Zealand. Infestations can reduce marketable yields greatly; reports of economic damage from its native and introduced ranges are summarised in Table 5 (for more detailed information on specific commodities see “Pathway Assessments”).

**Table 5: *Drosophila suzukii* – Summary of reported impacts on selected crops**

Crop	Reported impacts/damage	Overall impact <sup>21</sup>
Apricot ( <i>Prunus armeniaca</i> )	<ul style="list-style-type: none"> <li>• few reports of impacts in native range</li> <li>• few reports of damage in the US</li> <li>• recent reports of 20 to 50% of apricots in Italian orchards infested with eggs; eggs also detected on hard and unripe (green/orange) fruits (Grassi <i>et al.</i> 2011)</li> <li>• EPPO (2010f) reported “significant economic damage” (no reference)</li> </ul>	LOW TO MODERATE
blackberry ( <i>Rubus fruticosus</i> <sup>22</sup> )	<ul style="list-style-type: none"> <li>• maximum reported yield losses for blackberry crops in the USA were 50% (Bolda <i>et al.</i> 2010)</li> <li>• (EPPO factsheet 2010) reported significant economic damage on <i>Rubus</i> spp. (e.g. raspberries and blackberries)</li> </ul>	HIGH
blueberry ( <i>Vaccinium</i> spp.)	<ul style="list-style-type: none"> <li>• a significant pest of blueberries in China (ODA 2010a)</li> <li>• considered an economic pest throughout Japan (Tamada 2009)</li> <li>• causes significant economic damage (EPPO factsheet 2010)</li> <li>• 0 to 20% infestation reported in early season in Oregon (OSU 2009b)</li> <li>• maximum reported yield losses for blueberry crops in the USA were 40% (Bolda <i>et al.</i> 2010)</li> </ul>	HIGH
cherry ( <i>Prunus avium</i> )	<ul style="list-style-type: none"> <li>• Kanzawa (1935, Japan) surveyed orchards in 1931/1932 and reported that 5 % to 80 % of fruit was damaged</li> <li>• Kanzawa (1939) reported that 7 % to 75% of fruit on trees was damaged, and 0 to 55 % of harvested fruit was infested</li> <li>• causes significant economic damage (EPPO factsheet 2010)</li> <li>• significant damage reported in France (EPPO 2010b)</li> <li>• unconfirmed reports of 0.5 million kg of cherries diverted to internal markets (Shearer <i>et al.</i> 2010)</li> <li>• California: about one-third of cherry crop lost from Davis to Modesto (OSU 2009b); minimal to near 100% damage to sweet cherries in California depending on variety (Coates 2010); maximum reported yield losses for cherry crops in the USA were 33% (Bolda <i>et al.</i> 2010)</li> <li>• Over 90% of late harvested cherries in some Italian orchards were infested even when sprayed for <i>Rhagoletis cerasi</i> control</li> </ul>	HIGH
figs ( <i>Ficus</i> spp.)	<ul style="list-style-type: none"> <li>• Coates (2009) reported 30% damage in California</li> <li>• Grassi <i>et al.</i> (2011) reported that “many eggs had been counted on figs collected from [one] tree” in Italy</li> <li>• otherwise few reports of impacts in either native or introduced range</li> </ul>	LOW
grape ( <i>Vitis</i> spp.)	<ul style="list-style-type: none"> <li>• Kanzawa (1935) reported that “grapes being grown out in the open without bags over them had been completely wiped out” in the Akayu region of Japan</li> <li>• Kanzawa (1939) reported “The most pronounced damages on fruit trees are on cherries and grapes”</li> <li>• considered an economic pest throughout Japan (CFIA 2010)</li> <li>• few reports of economic damage in introduced range</li> </ul>	UNCERTAIN
hardy kiwi ( <i>Actinidia arguta</i> )	<ul style="list-style-type: none"> <li>• few reports of impacts in either native and introduced range</li> </ul>	LOW
peach ( <i>Prunus persica</i> )	<ul style="list-style-type: none"> <li>• causes significant economic damage (EPPO factsheet 2010)</li> <li>• destruction of 20% of Elberta peaches in an Oregon orchard (CPAN)</li> </ul>	MODERATE

<sup>21</sup> As reported in the literature

<sup>22</sup> used in an aggregate sense, to include most of *Rubus* sect. *Rubus*

Crop	Reported impacts/damage	Overall impact <sup>21</sup>
	2009) <ul style="list-style-type: none"> <li>losses of up to 80% in some orchards in Willamette Valley especially in late season (OSU 2009b)</li> </ul>	
nectarine ( <i>Prunus persica</i> var. <i>nucipersica</i> )	<ul style="list-style-type: none"> <li>few reports of serious damage to nectarine crops</li> </ul>	LOW
plums ( <i>Prunus domestica</i> and hybrids)	<ul style="list-style-type: none"> <li>100% damage to pluots (Coates 2009)</li> <li>causes significant economic damage to plums (EPPO factsheet 2010)</li> </ul>	UNCERTAIN
raspberry ( <i>Rubus</i> spp.)	<ul style="list-style-type: none"> <li>maximum reported yield losses for raspberry crops in the USA were 50% (Bolda <i>et al.</i> 2010)</li> <li>crop losses up to 20% reported in Oregon (OSU 2009b)</li> <li>EPPO (factsheet 2010) reported significant economic damage on <i>Rubus</i> spp. (e.g. raspberries and blackberries)</li> </ul>	HIGH
strawberry ( <i>Fragaria</i> spp.)	<ul style="list-style-type: none"> <li>causes significant economic damage (EPPO factsheet 2010)</li> <li>US reports of losses for this crop vary by location and end use</li> <li>yield losses of 20% have been reported in Oregon, while in California relatively little economic damage has been reported (Bolda <i>et al.</i> 2010)</li> <li>high impacts are predicted in the north-eastern USA (Cowles 2011)</li> <li>Grasi <i>et al.</i> (2011) reported negligible damage (2-3%) on Italian strawberries until the end of August, coinciding with scheduled sprays for other pests) but 60-80% damage recorded on the last harvested fruit of late ripening strawberries when insecticide pressure was reduced.</li> </ul>	MODERATE

Bolda *et al.* (2010) analysed the economic impacts of *D. suzukii* on US production and concluded that infestations have the potential to affect significant shares of certain crops. They predicted revenue losses to strawberry, blueberry, raspberry, blackberry and cherry crops, based on two scenarios: *i*) an average 20% yield loss and *ii*) maximum observed yield losses for each crop. For three states (California, Oregon and Washington), total losses for these crops for one year were estimated to be between \$420 and \$510 million USD<sup>23</sup>.

The Expert Working Group (EPPO 2010e) concluded that the potential for economic consequences due to *D. suzukii* incursions was high (with low uncertainty).

Experience from other countries suggests significant (moderate to severe) losses are likely to the following crops in New Zealand: blackberry, blueberry, cherry, strawberry and raspberry.

The major New Zealand horticulture industries by export earnings are wine (\$1.1 billion in 2010) and kiwifruit (\$1 billion in 2010)<sup>24</sup>.

- *Grapes*: impacts on grape production are uncertain. The export grape market in New Zealand is very small but any impacts on wine production would be very significant.
- *Kiwifruit*: there is no evidence that gold or green kiwifruit (*Actinidia chinensis* and *A. deliciosa* respectively) are hosts for *D. suzukii*. Hardy kiwis (kiwiberries or *A. arguta*) are confirmed hosts but there are no reports of significant impacts on this crop. Impacts on the kiwifruit industry would not be expected to be significant.
- *Summerfruit*: significant impacts could be expected on cherry and to a lesser extent peach and plum production (cherries are by far the most important summerfruit export by value). Around 70% of all summerfruit produced in New Zealand is consumed within the domestic market. The export market takes a further 25% with Taiwan, Australia and the USA being the predominant markets<sup>25</sup>.

<sup>23</sup> Several caveats were expressed around this analysis. The estimated yield losses were based on a limited number of field observations, and were also focused on a very limited set of host crops. *D. suzukii* has been observed on other hosts, and the full potential range of fruit and vegetable hosts is unknown.

<sup>24</sup> Source: [Situation and Outlook for New Zealand Agriculture and Forestry, 2010](#)

<sup>25</sup> Source: Summerfruit New Zealand (<http://www.summerfruitnz.co.nz/snz/index.php?zone=export&watp=0#>)

Establishment of *D. suzukii* is very likely to disrupt access to a number of key markets, such as Australia. In some cases, the detection of temporary populations of fruit flies can have market access impacts, even if the fruit fly is subsequently eradicated. Whether this occurs for *D. suzukii* will depend on the location of the detected population in relation to fruit-exporting areas and other factors.

Once developed, effective control methods will reduce realized yield losses in commercial production. However, the control measures will also raise production costs to an unknown extent. Control based on the regular application of broad spectrum insecticides has the potential to adversely affect integrated pest management programs and allow currently manageable pests to increase in importance. This has already been observed in the USA, e.g.:

- according to Isaacs *et al.* (2011), IPM programs for Michigan blueberries are at risk from SWD-triggered sprays
- Klick *et al.* (2011) reported that IPM programmes for berry and stone fruit the Pacific Northwest have been disrupted by full-cover applications of broad-spectrum pesticides used in response to *D. suzukii* infestations.

*The potential economic consequences of establishment are considered to be moderate to high.*

### **Environmental consequences**

*D. suzukii* is known to attack the fruit of nineteen plant families (Appendix 1), of which Rosaceae contains by far the most hosts. Most native Rosaceae, however, have dry fruit that are unsuitable hosts for *D. suzukii*. The only rosaceous genus that has native species with fleshy fruit is *Rubus* (Webb *et al.* 1988). *D. suzukii* is capable of infesting cultivated and wild *Rubus* species, and may also attack native *Rubus* (as well as other native species). There are five native species of *Rubus* but none is considered threatened (New Zealand Plant Conservation Network 2005). Regardless, the fly attacks only the flesh of ripe or ripening fruit and is unlikely to impair seed development, number or viability. It is possible that poor quality fruit resulting from larval feeding may reduce bird and mammal dispersal of seeds. Additionally, reduced availability of fruits through larval competition or highly damaged fruits may affect species that feed on the same fruit.

*Drosophila melanogaster* plays a major ecosystem role in vectoring micro-organisms (EOL 2009), and is assumed that *D. suzukii* is similar in being an effective vector for organisms such as bacteria and fungi. It is not known what impact this would have.

An incursion of *D. suzukii* would be likely to trigger a significant response, depending on the circumstances. Failing eradication, establishment of this species would require some form of long-term management. These interventions (eradication or management) will have some impact on the environment, for example the effects of large scale host removal or effects on populations of non-target species from the application of sprays.

Given that:

- the most commonly attacked family, Rosaceae, contains few species likely to be hosts
- ripe or ripening fruit is the only plant part attacked, and attack is unlikely to impair seed development, number or viability
- eradication or management of *D. suzukii* would be likely to have some environmental impacts;

*the potential environmental consequences of establishment are expected to be low.*

### **Socio-cultural consequences**

*D. suzukii* is likely to attack a range of fruit and vegetable crops. This may increase the price of commercially produced fruits, and backgarden fruit and vegetable growers would be likely to endure losses and may have to pay for additional treatments.

*The potential socio-cultural consequences of establishment are expected to be low.*

### **Human health consequences**

There are no anticipated human health consequences. According to Langellotto (2010), there is no evidence or history of any food-borne illness related to *D. suzukii*.

## **1.7 RISK ESTIMATION**

This risk estimation is for *Drosophila suzukii* on all approved commercial fresh produce pathways from the USA and one potential pathway. It does not cover countries other than the United States:

- The likelihood of entry is considered to be low to moderate for apricots and high for cherries, nectarines, peaches, plums, pluots, strawberries, table grapes and blueberries.
- The likelihood of exposure is considered to be high for adults and moderate for larvae and eggs.
- The likelihood of establishment and spread is considered to be high.
- The potential economic consequences of establishment are considered to be moderate to high, the potential environmental consequences and the socio-cultural consequences are considered to be low and the potential human health consequences are considered to be negligible.

As a result, the risk estimate for *D. suzukii* is non-negligible and this organism is classified as a hazard in these commodities. Therefore the risk is worth considering and further analysis may be undertaken to decide if additional measures are warranted.

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## APPENDIX 1: HOSTS OF *DROSOPHILA SUZUKII*

Host	Host association
Actinidiaceae	
<b><i>Actinidia arguta</i></b> <sup>26</sup> (hardy kiwi, kiwi berries)	reported as a “confirmed finding” (Dreves <i>et al.</i> 2009); reported as a host with no further information by EPPO (factsheet 2010) and as a host from Oregon with no further information by Acheampong (2010a); reported as an “other” ( <i>i.e.</i> not “most preferred”) host by OSU (2010b)
<i>Actinidia chinensis</i> (gold kiwifruit)	although there have been reports of “kiwifruit” or “ <i>Actinidia sp/p</i> ” as hosts, no specific records of <i>A. chinensis</i> as hosts of <i>D. suzukii</i> have been found
<i>Actinidia deliciosa</i> (green kiwifruit)	although there have been reports of “kiwifruit” or “ <i>Actinidia sp/p</i> ” as hosts, no specific records of <i>A. deliciosa</i> as hosts of <i>D. suzukii</i> have been found
Adoxaceae	
<i>Viburnum dilatatum</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010)
Cornaceae	
<i>Alangium platanifolium</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010)
<i>Cornus controversa</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010)
<i>Cornus kousa</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010). Recorded as a host in British Columbia by NAPPO (2010) and BCMAL (2009) with no further information
Cucurbitaceae	
There is no evidence for any species of Cucurbitaceae as hosts of <i>D. suzukii</i> . Kanzawa (1939) exposed whole melons, pickling melons ( <i>Cucumis melo</i> ), watermelons and pumpkins in laboratory oviposition tests and no flies emerged.	
Ebenaceae	
<i>Diospiros kaki</i> (persimmon)	Kanzawa (1935) reported fallen or damaged fruit as hosts <sup>27</sup> ; reared from damaged or dropped fruit in Japan; few adults emerged from ripe, split fruit collected in the field in Japan (Kanzawa 1939); reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010); reported to “feed on” persimmon in the USA (Acheampong 2010a); reported as an “other” ( <i>i.e.</i> not “most preferred”) host by OSU (2010b)
Elaeagnaceae	
<b><i>Elaeagnus multiflora</i></b> (silver berry)	few adults emerged from whole fruit collected in the wild (Kanzawa 1939); adults reared from ripe field-collected fruit (Sasaki & Sato 1995c). Kanzawa (1935) reported “oleaster” (used for <i>Elaeagnus angustifolia</i> and <i>E. latifolia</i> ) as a host
Ericaceae	
<i>Gaultheria adenostrix</i>	reared from fallen fruit collected at high altitude in Japan (Mitsui <i>et al.</i> 2010)
<b><i>Vaccinium spp.</i></b> (blueberries)	many adults reared from ripe field-collected fruit in Japan (Sasaki & Sato 1995c); reared from fallen “ <i>Vaccinium spp.</i> ” fruit collected at high altitude in Japan (Mitsui <i>et al.</i> 2010); reported as a “confirmed finding” in “blueberries” (Dreves <i>et al.</i> 2009, OSU 2009a, BCMAL 2009); blueberries reported as a “most preferred” host by OSU (2010b); confirmed attacking fruit on commercial <i>Vaccinium</i> (blueberry) plants in Florida (FDACS 2010); EPPO factsheet (2010) reports significant economic damage
Garryaceae	
<i>Aucuba japonica</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010)
Grossulariaceae	
<i>Ribes spp.</i> (blackcurrant, redcurrant, gooseberry)	“ <i>Ribes</i> ” reported as a host (NAPPO 2010) with no further information. Biosecurity Australia (2010) reports “Canadian authorities have confirmed <i>Ribes spp.</i> are hosts only when damaged (pers. comm., Martin Damus, CFIA, 22 April 2010)
Moraceae	
<b><i>Ficus carica</i></b> (common fig)	reported as a “confirmed finding” in figs (Dreves <i>et al.</i> 2009); reported as an “other” ( <i>i.e.</i> not “most preferred”) host by OSU (2010b); reported as a host by Acheampong (2010a) and EPPO (Alert List 2010) with no further information; 30% damage reported in California (Coates 2009). Biosecurity Australia (2010) reports “Figs have only been recorded to be attacked

<sup>26</sup> **Species in bold:** there is considered to be sufficient evidence to regard trade in fresh produce of these species as potential pathways for *Drosophila suzukii* introduction

<sup>27</sup> Although Kanzawa refers to “ripe” persimmons as hosts in the text of his paper, he later divides hosts according to whether they are infested as “perfect” fruit or fallen/damaged fruit, and persimmons are included in the latter category

Host	Host association
	when the fruit is over-ripe (Pers. comm., Vaughn Walton, OSU 12 October 2010)."
<b><i>Morus alba</i></b> (mulberry)	Kanzawa (1935) reported "perfect" fruit as hosts; few adults emerged from whole fruit collected from wild in Japan (Kanzawa 1939); adults reared from ripe field-collected fruit (Sasaki & Sato 1995c)
<i>Morus australis</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010, as <i>Morus bombycis</i> )
<b><i>Morus rubra</i></b> (red mulberry)	confirmed attacking fruit on plants in Florida (FDACS 2010)
Musaceae	
<i>Musa</i> spp. (bananas)	ripe bananas can be used as attractants for monitoring (Wu <i>et al.</i> 2007, OSU 2009a) but there are no reports of intact fruit as a host
Myricaceae	
<i>Myrica rubra</i> (red bayberry)	<i>D. suzukii</i> was the dominant species in a bayberry orchard in Yunnan, China, mainly infesting fallen fruit (Wu <i>et al.</i> 2007)
Myrtaceae	
<b><i>Eugenia uniflora</i></b> (Surinam cherry)	confirmed attacking fruit on plants in Florida (FDACS 2010)
<i>Psidium cattleianum</i> (strawberry guava)	Many reared from rotting fruit (Kido <i>et al.</i> 1996)
Phytolaccaceae	
<b><i>Phytolacca americana</i></b> (pokeweed)	adults reared from ripe field-collected fruit (Sasaki & Sato 1995c)
Rosaceae	
<i>Eriobotrya japonica</i> (loquat)	Kanzawa (1935) reported fallen or damaged fruit as hosts in Japan; few adults emerged from cut fruit reared in the lab, none emerged from whole fruit (Kanzawa 1939); reported to "feed on" loquat in the USA (Acheampong 2010a); collected from fallen fruit on the ground in Florida (FDACS 2010)
<b><i>Fragaria ananassa</i></b> (strawberry)	Kanzawa (1935) reported "perfect" fruit as hosts; many adults emerged from whole fruit collected in the wild in Japan (Kanzawa 1939); reported as a "confirmed finding" (Dreves <i>et al.</i> 2009); reported as a "most preferred" host by OSU (2010b); confirmed attacking fruit on commercial strawberry plants in Florida (FDACS 2010); EPPO factsheet (2010) reports significant economic damage to strawberries
<b><i>Fragaria grandifolia</i></b>	whole fruit reported as hosts (Kanzawa 1939)
<i>Malus</i> spp. (apple)	Kanzawa (1935) reported fallen or damaged fruit as hosts; reported to "feed on" apple in the USA (Acheampong 2010a); Kanzawa (1939) reported damaged " <i>Malus pumila vardomestica</i> " as hosts, and few adults emerging from damaged apples reared in the laboratory in Japan; can be present in already damaged fruits (EPPO factsheet 2010). Coates (2009) reported 75% damage to Jonagold apples and 20% damage to Spigold 20% damage in California (other varieties only over-ripe or damaged fruit infested); damaged apple reported as an "other" ( <i>i.e.</i> not "most preferred") host by OSU (2010b)
<b><i>Prunus armeniaca</i></b> (apricot)	Kanzawa (1935) reported fallen or damaged fruit as hosts; few adults emerged from damaged or dropped fruit collected in the wild in Japan (Kanzawa 1939); Coates (2009) reported that no apricots in commercial orchards in California were attacked, except very late, over-ripe or damaged fruit even when grown near infested cherries; reported to "feed on" apricot in the USA (Acheampong 2010a); Shearer <i>et al.</i> (2010) reported larval contamination in commercial apricots in British Columbia in 2010. Steenwyk (2010) reports apricot (and tomato) as "Not hosts at this time". Grassi <i>et al.</i> (2011) reported eggs and larvae in apricots in Italy.
<b><i>Prunus avium</i></b> (sweet cherry)	cherries "greatly impacted" in Japan in the 1930s (Kanzawa 1935); many adults emerged from whole fruit collected in the wild in Japan (Kanzawa 1939); reported as a "confirmed finding" in cherries (Dreves <i>et al.</i> 2009); minimal to near 100% damage to sweet cherries reported in California (Coates 2010); significant economic damage to sweet cherries reported (EPPO factsheet 2010); reported as a "most preferred" host by OSU (2010b); larval contamination in commercial sweet cherries in British Columbia reported (Shearer <i>et al.</i> 2010); more than 90% of late harvested cherries in some orchards in Italy infested, even when sprayed for <i>Rhagoletis cerasi</i> control (Grassi <i>et al.</i> 2011).
<b><i>Prunus buergeriana</i></b> (Shirozakura)	adults reared from ripe field-collected fruit (Sasaki & Sato 1995c)

Host	Host association
<b><i>Prunus cerasus</i></b> (dwarf cherry)	reared from whole fruit (Kanzawa 1939)
<b><i>Prunus domestica</i> and hybrids</b> (plums etc.)	“ripe and fallen fruit” reported as hosts by Kanzawa (1935); few adults emerged from whole Terada plums collected in the field and many emerged from overripe and cut Terada and White Beauty plums reared in the lab in Japan (Kanzawa 1939); 100% damage to pluots reported in California (Coates 2009); reported as a “confirmed finding” in plums (Dreves <i>et al.</i> 2009); Shearer <i>et al.</i> (2010) reported damage to plums in Oregon; EPPO factsheet (2010) reports significant economic damage; plumcots and Satsyma plums reported as “other” ( <i>i.e.</i> not “most preferred”) hosts by OSU (2010b)
<b><i>Prunus donarium</i></b>	Many emerged from whole fruit collected from the wild in Japan (Kanzawa 1939)
<b><i>Prunus japonica</i></b> (Korean cherry)	Kanzawa (1935) reported “perfect” fruit as hosts; many adults emerged from whole fruit collected from wild (Kanzawa 1939)
<b><i>Prunus mahaleb</i></b> (Mahaleb cherry)	Kanzawa (1935) reported “perfect” fruit as hosts; many adults emerged from whole fruit collected in the wild (Kanzawa 1939)
<b><i>Prunus mume</i></b> (Japanese apricot)	reported as a host of Japanese apricot by Acheampong (2010a) and Hauser and Damus (2009)
<i>Prunus nipponica</i>	reared from fallen fruit collected at high altitude in Japan (Mitsui <i>et al.</i> 2010)
<b><i>Prunus persica</i></b> (peach)	“ripe and fallen fruit” reported as hosts by Kanzawa (1935); many adults emerged from damaged or dropped fruit collected in the field, and from unripe and ripe cut fruit in the laboratory (Kanzawa 1939); Sasaki & Sato (1995c) confirmed that healthy peach fruit is infested; reported as a “confirmed finding” in Oregon (Dreves <i>et al.</i> 2009); Coates (2009) reported that soft, tree ripe peaches were hosts in commercial orchards in California; reported as a “most preferred” host by OSU (2010b); Shearer <i>et al.</i> (2010) reported larval contamination in commercial peach in British Columbia; EPPO factsheet (2010) reports significant economic damage
<b><i>Prunus persica</i> var. <i>nucipersica</i></b> (nectarine)	reported as a host by Acheampong (2010a); reported as an “other” ( <i>i.e.</i> not “most preferred”) host by OSU (2010b)
<i>Prunus salicina</i> (Japanese plum)	reported to “feed on” Japanese plum in the USA (Acheampong 2010a)
<b><i>Prunus sargentii</i></b> (Sargents cherry)	Kanzawa (1935) reported “perfect” fruit as hosts
<b><i>Prunus serotina</i> subsp. <i>capuli</i></b> (Capulin cherries)	100% damage in California (Coates 2009; as <i>Prunus salicifolia</i> )
<i>Prunus serrulata</i> var. <i>spontanea</i> (= <i>Prunus jamasakura</i> )	Sasaki & Sato (1995c) state that Kanzawa (1939) confirmed that healthy “wild cherries ( <i>Prunus jamasakura</i> )” were hosts; however Kanzawa refers to “Wild Cherry” as <i>P. donarium</i> , not <i>P. jamasakura</i>
<i>Prunus triflora</i>	damaged or dropped fruit (Kanzawa 1939)
<b><i>Prunus yedonensis</i></b> (Somei Yoshino)	Kanzawa (1935) reported “perfect” fruit as hosts; many adults emerged from whole fruit collected from the wild (Kanzawa 1939); adults reared from ripe field-collected fruit (Sasaki & Sato 1995c).
<b><i>Pyrus pyrifolia</i></b> (Asian pears, Nashi pears)	some adults reared from fruit in the laboratory (Kanzawa 1935); reported as a “confirmed finding” in Asian pears (Dreves <i>et al.</i> 2009); many emerged from cut fruit reared in the lab in Japan (Kanzawa 1939); reported as a host by EPPO factsheet (2010) and Acheampong (2010a)
<i>Pyrus ussuriensis</i>	cut fruit (Kanzawa 1939, as <i>Pirus sinensis</i> , Lindlb.)
<b><i>Rubus fruticosus</i></b> <sup>28</sup> (blackberries)	adults reared from ripe field-collected fruit (Sasaki & Sato 1995c); “wild blackberries” reported as a “confirmed finding” (Dreves <i>et al.</i> 2009); confirmed infesting wild & cultivated blackberry ( <i>Rubus</i> ) in British Columbia (BCMAL 2009); 20% damage in California (Coates 2009); “blackberries” reported as a host by Acheampong (2010a) with no further information; EPPO factsheet (2010) reports significant economic damage; “Blackberries” are reported as a “most preferred” host by OSU (2010b)
<b><i>Rubus armeniacus</i></b> (Himalayan blackberry)	reported as a host (EPPO Alert List 2010); reported as a host in British Columbia (Acheampong 2010a)
<i>Rubus crataegifolius</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010)
<b><i>Rubus hirsutus</i></b>	wild <i>Rubus hirsutus</i> reported as a host by Kanzawa (1935)
<b><i>Rubus idaeus</i></b>	Kanzawa (1935) reported “perfect” fruit as hosts; adults reared from ripe field-

<sup>28</sup> used in an aggregate sense, to include most of *Rubus* sect. *Rubus*

Host	Host association
(raspberries)	collected fruit (Sasaki & Sato 1995c); reported as a “confirmed finding” in red raspberries (Dreves <i>et al.</i> 2009); confirmed infesting fall raspberry ( <i>Rubus</i> ) in British Columbia (BCMAL 2009); 100% damage in California (Coates 2009); EPPO factsheet (2010) reports significant economic damage; reported as a “most preferred” host by (OSU 2010b)
<b><i>Rubus incises</i></b> (Japanese raspberry)	whole fruit reported as hosts, many adults emerged from whole fruit of “Japanese Raspberry ( <i>Rubus incises/ R. microphyllus</i> )” collected from wild (Kanzawa 1939)
<b><i>Rubus laciniatus</i></b> (evergreen blackberry)	reported as a host (EPPO Alert List 2010)
<b><i>Rubus loganobaccus</i></b> (boysenberry)	reported as a “most preferred” host by OSU (2010b); reported as a host with no further information by Acheampong (2010a) and EPPO Alert List (2010; as <i>R. loganobaccus/ loganberries</i> )
<b><i>Rubus microphyllus</i></b>	Kanzawa (1939) reported that many adults emerged from whole fruit of “Japanese Raspberry ( <i>Rubus incises/ R. microphyllus</i> )” collected from wild; reared from fallen fruit collected at high altitude in Japan (Mitsui <i>et al.</i> 2010)
<b><i>Rubus parvifolius</i></b> (Japanese raspberry)	many emerged from whole fruit reared in the lab (Kanzawa 1939)
<b><i>Rubus triphyllus</i></b> (threeleaf blackberry)	adults reared from ripe field-collected fruit (Sasaki & Sato 1995c); many emerged from whole fruit collected from the wild in Japan (Kanzawa 1939)
<b>Marionberries</b>	reported as a “confirmed finding” in marionberries (Dreves <i>et al.</i> 2009); also reported with no further information by EPPO Alert List (2010; as <i>Rubus ursinus</i> ) and Acheampong (2010a)
Rutaceae	
<i>Citrus</i> spp.	old fallen citrus (Price & Nagle 2009); trapped in citrus orchards with fallen citrus fruit (Walsh <i>et al.</i> 2011)
<b><i>Murraya paniculata</i></b> (orange jessamine)	confirmed attacking fruit on plants in Florida (FDACS 2010)
Solanaceae	
<i>Lycopersicon esculentum</i> (tomato)	Kanzawa (1935) reported fallen or damaged fruit as hosts and some adults reared from fruit in the laboratory; few adults emerged from cut fruit reared in the lab in Japan and none emerged from whole fruit (Kanzawa 1939); ODA (2010a) report as a host in the laboratory; reported to “feed on” tomato in the USA (Acheampong 2010a); collected from fallen fruit on the ground in Florida (FDACS 2010). Steenwyk (2010) reports tomato (and apricot) as “Not hosts at this time”
Styracaceae	
<b><i>Styrax japonicus</i></b>	reared from flowers collected at low altitude in Japan (Mitsui <i>et al.</i> 2010); Biosecurity Australia (2010) cites correspondence with M. Damus confirming association
Taxaceae	
<i>Torreya nucifera</i>	reared from fallen fruit collected at low altitude in Japan (Mitsui <i>et al.</i> 2010)
Vitaceae	
<b><i>Vitis vinifera</i></b> (grapes)	“perfect” fruit reported as hosts by Kanzawa (1935); whole fruit reported as hosts, with few to many adults emerging from whole fruit collected in the wild depending on grape variety; in some cultivars ( <i>e.g.</i> Koshu and Delaware) the skin was too thick for the ovipositor to be inserted (Kanzawa 1939); reported as a “confirmed finding” in grapes (Dreves <i>et al.</i> 2009); confirmed infesting grape ( <i>Vitis</i> ) in British Columbia (BCMAL 2009); reported as a “most preferred” host by OSU (2010b); reported as a field host in Italy (Cini <i>et al.</i> 2012)

## APPENDIX 2: SUMMARY OF APPROVED COMMODITIES – UNITED STATES OF AMERICA

Commodity Scientific Name	Commodity common name	Evidence that trade could be a pathway for SWD?
<b>APPROVED COMMODITIES</b>		
<i>Actinidia deliciosa</i>	Green Kiwifruit	No
<i>Allium cepa</i>	Onion/Shallots	No
<i>Allium sativum</i>	Garlic	No
<i>Asparagus officinalis</i>	Asparagus	No
<i>Carica papaya</i>	Papaya	No
<i>Citrus aurantiifolia</i>	Lime	No
<i>Citrus limon</i>	Lemon	No
<i>Citrus paradisi</i>	Grapefruit	No
<i>Citrus reticulata</i>	Mandarin/ Tangerine	No
<i>Citrus sinensis</i>	Orange	No
<i>Citrus paradisi</i> x <i>C. reticulata</i>	Tangelo	No
<i>Citrus maxima</i>	Pomelo	No
<i>Fragaria</i> sp.	Strawberry	<b>YES</b>
<i>Malus x domestica</i>	Apple	No
<i>Mangifera indica</i>	Mango	No
<i>Pisum sativum</i>	Peas, Green/ Snow/ Sugar Snap	No
<i>Phoenix dactylifera</i>	Dates (Fresh)	No
<i>Prunus armeniaca</i>	Apricot	<b>YES</b>
<i>Prunus avium</i> (California)	Cherry	<b>YES</b>
<i>Prunus avium</i> (Idaho, Oregon, Washington)	Cherry	<b>YES</b>
<i>Prunus domestica</i>	Plum	<b>YES</b>
<i>Prunus persica</i>	Nectarine/Peach	<b>YES</b>
<i>Punica granatum</i>	Pomegranate	No
<i>Pyrus communis</i>	Pear	No
<i>Vitis vinifera</i> .	Grape	<b>YES<sup>29</sup></b>
<b>NON APPROVED COMMODITIES</b>		
<i>Rubus</i> spp.	Caneberries	<b>YES</b>
<i>Vaccinium augustifolium</i> and <i>V. corymbosum</i>	Blueberry	<b>YES</b>

<sup>29</sup> With a high degree of uncertainty